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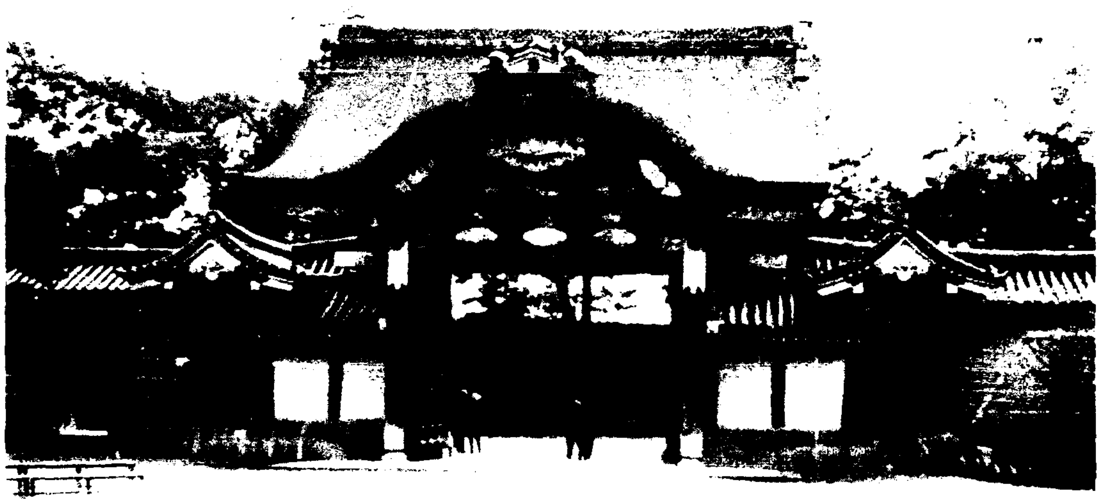

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This is a quarterly publication presenting articles covering recent developments in Far Eastern (particularly Japanese) scientific research. It is hoped that these reports (which do not constitute part of the scientific literature) will prove to be of value to scientists by providing items of interest well in advance of the usual scientific publications. The articles are written primarily by members of the staff of ONR Far East, the Air Force Office of Scientific Research, and the Army Research Office, with certain reports also being contributed by visiting stateside scientists. Occasionally, a regional scientist will be invited to submit an article covering his own work, considered to be of special interest. This publication is approved for official dissemination of technical and scientific information of interest to the Defense research community and the scientific community at large.

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PAN-based fiber producers
Superconductivity
Microstructure and vortex pinning
Navier/Stokes benchmark
Pitch-based fiber producers
Organized assemblies of synthetic molecules
Bioelectronic devices
Japanese management
Kaizen
Quality function deployment
Korea
Cryogenic technology

Martensitic transformations
Diffusion
Spinodal decomposition
R&D in the private sector
Research collaboration
Materials fundamentals
Materials reliability
Carbon fiber manufacturing processes
Precursor materials
Mechanical properties of carbon fibers
Electromagnetic properties
Supercomputers
Fujii/Obayashi code
Langmuir-Blodgett method
Informational neuroscience
Organized assemblies of biomolecules
Quality control
Quality tools
Poke-Yoke
Aramid fiber
Sputtered films

In Memoriam

The friends of Eunice Mohri will be saddened to learn of her death March 16 from a heart attack. She is survived by her sister Florence Mohri of 5597 Seminary Road, Falls Church, VA 22041. Memorial contributions may be made to the Section of Cardiology, Department of Medicine, George Washington University Hospital, 901 23rd Street N.W., Washington, DC 20037, or a charity of your choice. It is requested that no flowers be sent to the house.

Eunice, who was 72, worked for the Office of Naval Research for 42 years in many capacities. Her last position was historian for ONR. Whatever the task, she did it with enthusiasm and a determination to achieve the best; this was recognized by two Meritorious Civilian Service Awards and 14 awards for special achievements and outstanding performance. More than such formal recognition was the love and respect she had from her colleagues. She was a friend, counsellor, and support to many whose lives intersected with hers.

A native of Bakersfield, CA, Eunice received a degree from Santa Barbara State Teachers College and later a B.A. from the University of California, Santa Barbara. After several years with the Office of Indian Affairs, Eunice began working in 1947 at the Chicago Branch Office of ONR. In 1957 she came to ONR Headquarters as senior administrative assistant for the Naval Analysis Program. Then in April 1975 she went to Tokyo to set up the ONR Office before the scientific staff arrived. For 5 years she served as the administrative officer at the Tokyo Office and associate editor for the ONR Far East's Scientific Bulletin. While in Japan she worked hard to encourage young people from the U.S. and Japan to learn about each other and their countries. From 1980 to 1986 Eunice was again at ONR Headquarters as staff assistant to the Naval Research Advisory Committee. In 1986 she retired from Federal service but continued working part-time in the historian's office organizing the symposia and publications connected with ONR's 40th birthday. She was proud to work for ONR and its goals and programs.

Eunice was an optimist about people even in the most trying times. She was an outstanding person whose diligence, gentle wit, and empathy for life will be missed by many.

OVERSEAS LIAISON SCIENTIST POSITIONS
TOKYO, JAPAN

The Office of Naval Research, the Air Force Office of Scientific Research, and the Army Research Office are jointly soliciting letters of interest and resumes from qualified candidates to fill liaison scientist positions in their combined office in Tokyo. Candidates are sought who are U.S. citizens, are currently research scientists or research engineers, and who have a Ph.D. or equivalent experience in physical, environmental, engineering, or life sciences. In general, preference is given to candidates from the academic or government sectors. Knowledge of DOD R&D activities, relevant, established foreign contacts, and stature in the international R&D community are highly desirable features of an applicant's background.

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Candidates should send letters of interest (indicating dates of availability) and resumes to: Ms. Pearl Cano, Office of Naval Research, International Programs (Code 11D5), Arlington, VA 22217-5000.

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Cover: Gate at Nijo-jo, Kyoto. Nijo Castle, built in 1603, was the residence of Ieyasu, the first Shogun of the Tokugawa family. The gate shown is the Kara-mon Gate, which is richly ornamented with wood carvings and metalwork. Courtesy of Earl Callen.

JAPANESE RESEARCH ON METASTABLE PHASES OF METALS AND ALLOYS

Earl Callen, Fred Pettit, and Paul Shingu

The capability to produce metastable phases is opening new approaches to the synthesis of engineering materials. Metastability involves two kinds of concepts: "trapped" phases or states with energies higher than the equilibrium state and the kinetics of getting into and out of those states. Phase diagrams and their relation to the Gibbs free energies of various phases are used to illustrate various types of transformations. In current Japanese research, rapid solidification, mechanical alloying, irradiation-induced modification of surfaces, and a variety of vapor phase processes have been used to form metastable phases. The important requirements that must be satisfied to develop metastable phases are discussed in terms of a step sequence, extensions of equilibrium phase boundaries, and the interaction energies between like and unlike atoms.

INTRODUCTION

Although the intensive study of metastability is relatively recent, the use of metastable phases to develop desired properties and characteristics in metals and alloys is not new. For example, in the early years of this century Alfred Wilm discovered that aluminum alloys with a few percent Cu, if water quenched to room temperature, gradually increased in strength over time. That this was due to the precipitation and slow growth of fine precipitates--so-called Guinier-Preston zones--could not be directly confirmed with light microscopy because the size of the precipitate particles is less than optical wavelengths. Observation had to wait for the new instrumentation of electron microscopy.

The dramatic increase in research on metastable phases within the past 10 to 15 years and the awareness of their importance as a means of developing materials with unique properties are consequences of new techniques for producing metastable phases. Rapid solidification, laser glazing, high energy electron irradiation, ion irradiation and ion beam mixing, sputtering and other forms of vapor phase quenching, and mechanical alloying are all recently explored techniques by which metastable phases can be formed, modified, and studied. Some of these techniques are suitable for production of metastable materials on a scale compatible with commercial utilization.

This paper is concerned with Japanese research on metastability. But first we must decide what is metastability, what are the principal processes by which it can be attained, what are the logical concepts--primarily thermodynamic considerations--that allow us to understand it? Those questions will be answered and elaborated on with examples from Japanese research.

Thermodynamics concerns itself with equilibrium systems and the "close by" evolution toward equilibrium. Even when constraints are altered, processes are assumed to be carried out sufficiently slowly that the system follows in quasi-static equilibrium. When a system is not in equilibrium it will evolve to an equilibrium state, the state of lowest Helmholtz or Gibbs free energy, if one waits long enough. In solids, particularly when attainment of equilibrium requires macroscopic mass diffusion, relaxation times can be long, and there are often metastable states in which the system can become trapped. Metastable states are of increasing importance--amorphous metals, the new iron-rich permanent magnets, epitaxial films, icosahedral quasicrystals. Diamond is metastable. Graphite has a lower free energy at room temperature and atmospheric pressure. Galaxies should be mostly iron and radiation. While less cosmic, martensitic steels and quenched aluminum alloys are good examples of the issue. An important part of metallurgy is the development of useful materials, often through processes taking advantage of metastability.

METASTABILITY

What is metastability? One starts with an intuitive microscopic picture, carried over from physics and chemistry, of an energy curve with a minimum at some spatial coordinate, a barrier, and a deeper minimum. A particle can be trapped in a local well with insufficient energy to get over the barrier to the deeper minimum. The barrier can be surmounted in two ways. Quantum mechanically--if one waits long enough the particle will tunnel through. How long this takes depends upon the height and width of the barrier and the energy of the particle.* More practically, except at $T=0$ there are thermal fluctuations, and if one waits long enough a sufficiently large fluctuation will excite the particle over the barrier. Metastability, therefore, implies waiting less than some relaxation time.

But this is at the atomic level. Is the concept more sharply defined for large systems? For macroscopic systems, unequivocally, the phase that is stable, the equilibrium phase, is the one of lowest Gibbs free energy. The free energy of a system in a metastable state can be lowered by a transformation, but the problem of describing how long metastability will endure is more involved. Kinetic processes control the rates of transformation. In transformations consisting of nucleation and growth, metastability can be considered to be "transitory" because in principle processes are continually occurring to develop the stable phase. In practice, however, depending upon the temperature, these processes can be so slow that the metastable phase can be considered to endure "indefinitely."

In cooperative transformations, such as order-disorder and martensitic transformations, temperature is a very critical parameter. If an alloy had an atomically ordered ground state and an atomically ordered higher energy state of different arrangement, and if the system could be trapped in the excited ordered arrangement at low temperature, there would be no small energy, local way to transform, and metastability could last "forever."

Turnbull (Ref 1) categorizes metastable structures into three groups: compositional, structural, and morphological. Compositionally metastable systems are those in which a different spatial distribution of the components would have a lower free energy. An example is an undercooled homogeneous alloy whose free energy would be reduced by segregating into an inhomogeneous mixture of two phases. In structurally metastable systems a lattice structure of

*The transmission coefficient of a particle of mass m is proportional to $\exp(-m^{1/2})$, so the lifetime in the well goes as $m^{1/2}$. The ratio of lifetimes in the well for escape by atomic quantum tunneling to that for electron tunneling goes as $(M/m)^{1/2}$, a factor of about 300 for iron.

different symmetry would have a lower free energy. An example is an amorphous solid. Morphologically metastable systems include those with a thermodynamically excessive number of imperfections--dislocations, interfaces, systems with incoherent interphase boundaries, microcrystalline materials, and compositionally modulated films. The excess energy per mole stored in the system, the energy above the equilibrium state, differs among the three categories. Turnbull estimates the excess energy. Compositionally metastable systems have an excess energy of up to RT_m or so; structurally metastable systems, about 0.5 RT_m, and morphological systems have an excess energy of less than 0.1 RT_m, where T_m is the average melting temperature of the components in each case.

The general procedure in developing metastable phases is to energize and quench. The material is energized by vaporizing, melting, cold working, ion bombardment. It is then rapidly cooled and kinetically trapped in the metastable phase. One needs to understand the selection rules, the transition probabilities, from the excited state through whatever sequences of states the system progresses, and what determines at which state in the sequence the procession stops and the system is trapped. Ostwald (Ref 2) proposed a "step rule" that usually a metastable phase appears first, and that this in turn decomposes to the stable phase. The more general expression of the step rule is that a system will evolve successively through a progression of metastable states in order of decreasing free energy. Turnbull (Ref 1) proposes that in structural transformations the evolution is through states with entropy closest to the initial excited state. "The processes favored kinetically are likely to be those requiring the smallest changes in the positional and motional correlations of the atoms in the evolving group and it is such processes that should be attended by the least entropy change." Turnbull cites a number of examples supporting a step "minimum entropy change" transformation sequence and also shows some apparent exceptions. In conformance with the principle, amorphous rather than crystalline films often deposit from the vapor on very low temperature amorphous substrates. On the other hand, pure metals generally deposit from their vapors in polycrystalline forms on cold substrates. Turnbull explains that this can happen when the number per unit area of heterophase nucleants on the substrate is high. There is evidence that the movement of the crystal/amorphous interface in pure monatomic systems is not quench suppressible. We shall examine recent Japanese vapor phase quenching work with results both supporting and at variance with the "least entropy change" step transformation sequence.

Martensitic transformations, order-disorder transformations in alloys, and single atom, diffusive transformations are so different in nature that one cannot expect transformations of these different kinds to interleaf in a step sequence. As discussed by Turnbull, the sequence that is followed depends upon a number of factors that include the type of phase being quenched, the temperature of the substrate, the rate of quenching, and the availability of nucleants. For example, in contrast with melt quenching, there should be no limit on the composition ranges of solid solutions formable by vapor condensation, since attractive interactions between unlike as well as between like atoms are always longer range than repulsive ones. It should therefore be possible to codeposit from the vapor as solid solutions elements with only limited liquid state miscibilities.

Moreover, amorphous solids formed by vapor condensation should be less relaxed structurally, or more disordered, than those with the same composition made by melt quenching. In recent Japanese research a rationale for the step rule is given for those transformation sequences in which the daughter phase forms by nucleation and growth. This will be examined later.

We require some limitations. There is a large body of important work, theoretical and experimental, on the material properties of composites--for example, superconductors with ferromagnets. That is not what this article is about. What we wish to explore is the stability and state of the material itself, its "thermodynamics." Potentially there are an almost infinite number of elements and compounds to be mixed together and many ways of mixing or depositing them; we limit ourselves to metals (mostly). We are interested in gas phase, liquid phase, and solid state reactions, in amorphous materials and in polycrystal aggregates. We shall not discuss icosahedral quasicrystals.

Metallurgists live with and understand metastability. So to begin we describe phase diagrams, equilibrium and otherwise, such as are covered in a metallurgy text (Ref 3,4). Reference 3 is particularly recommended.

GIBBS FREE ENERGY: WHAT EVERY METALLURGIST KNOWS

Since the intensive variables, pressure and temperature, are more easily controlled, the convenient thermodynamic potential is the Gibbs free energy. In reality, except under extreme pressure the energy stored in volume changes is so small compared to the chemical and mechanical energies to be dealt with that the pressure term is ignored and the internal energy and enthalpy treated interchangeably. Except for two examples, we shall not be concerned with pressure effects, only with temperature and composition, and we shall restrict ourselves to at most two component systems. Box 1 describes the Gibbs free energy of binary alloys.

Box 1. Gibbs Free Energy of Alloys

Single Component Systems

Ignoring pressure contributions, since

$$\frac{\partial G}{\partial T} = -S \quad \text{and} \quad \frac{\partial S}{\partial T} = \frac{C_p}{T}$$

$$G = G_o - \int_o^T S\,dT = G_o - \int_o^T \int_o^T C_p\, d(\ln T)\, dT \qquad \text{(B1-1)}$$

The free energy of a substance decreases as the temperature and entropy increase and decreases with greater curvature the larger the specific heat. G_o is a constant, the internal energy at T=0. To use Equation B1-1 one must know the specific heat of a particular phase from T=0 up to temperature T. The phase in question may not be stable over this entire temperature range, and the specific heat of the phase must then be found either theoretically, or by extrapolation, or by measurements on the material in a metastable situation in which the

Box 1. Continued

phase is expressed. Such procedures allow comparison of free energies of different possible phases. Another, perhaps more practical approach is to integrate Equation B1-1 through the appropriate temperature ranges and with the appropriate specific heats of the successive equilibrium phases, and including latent heats at all transitions, up to the phase and temperature in question.

In polymorphic transformations the phase with lower internal energy will be stable at low temperatures but the phase with higher entropy (i.e., of larger integrated specific heat) will have a lower free energy at higher temperature. For example, since close-packed structures (e.g., face centered) generally have lower internal energy, and more open structures (simple, or body centered) tend to have larger entropies, polymorphic transformations often go from close-packed to more open structures with increasing temperature.

Binary Alloys; Entropy of Mixing

In the expression above for the free energy of a single component substance, entropy contributions appear via the specific heat term. In the case of a solution of two components there is another, extremely important contribution to the entropy and free energy that comes from the mixing of the components. In a solution of n_A moles of component A and n_B moles of component B the total free energy is

$$G = x_A G_A + x_B G_B \qquad \text{(B1-2)}$$

where

$$x_A = n_A/n, \qquad x_B = n_B/n, \qquad n = n_A + n_B \qquad \text{(B1-3)}$$

and

$$G_i = G_i^\circ + n_i RT \ln a_i; \qquad i = A,B \qquad \text{(B1-4)}$$

$$a_i = \gamma_i x_i \qquad \text{(B1-5)}$$

G_i is the partial free energy of n_i moles of component i, G_i° is the free energy of n_i moles of pure component i, a_i is the activity of component i in solution, and γ_i is the activity coefficient of i. If the interaction between components A and B is ideal (the interaction energy is the same between like and unlike elements, $\gamma_A = \gamma_B = 1$) and the mixing is random, the activities reduce to the mole fractions:

$$G = x_A G_A^\circ + x_B G_B^\circ + n RT(x_A \ln x_A + x_B \ln x_B) \qquad \text{(B1-6)}$$

The first two terms, additive in the mole fraction, vary linearly from the Gibbs free energy of pure A to that of pure B as the concentration is varied. The Gibbs free energy terms for the pure elements are those of expression B1-1 above. The mixing term (it is negative) is zero at

Box 1. Continued

the two extremes and is a minimum at $x_A = x_B = 1/2$. The sum of the three terms will have a minimum at some intermediate concentration. At low temperature the mixing term makes only a small contribution to the free energy of the solution, but at high temperature it can be dominant in fixing phase boundaries. Because of the nature of the logarithm, G approaches both boundaries with infinite slope and all higher derivatives infinite. G is graphed in Figure 1. Under the simplifying assumptions of an ideal solution, G has positive curvature everywhere. This reflects the fact that for any (partially) inhomogeneous mixture of two compositions, the entropy of mixing can be further increased and the Gibbs free energy further reduced by homogenization, which will thus happen spontaneously via diffusion (if one waits long enough).

In the case of solutions that are not ideal the expression for G is

$$G = x_A G_A^\circ + x_B G_B^\circ + n\,RT(x_A \ln x_A + x_B \ln x_B) + n\,RT(x_A \ln \gamma_A + x_B \ln \gamma_B) \quad \text{(B1-7)}$$

If we assume a regular solution (i.e., a nonzero heat of mixing but an ideal entropy of mixing), then the last group of terms on the right side of Equation B1-7 can be replaced by $n\Delta H_m$, where ΔH_m is the molar heat of mixing. The heat of mixing can be approximated by assuming its value is determined entirely from the interaction between nearest neighbor pairs (i.e., the quasi-chemical model) whereby

$$\Delta H_m = x_A x_B (Nz/2)(2 V_{AB} - V_{AA} - V_{BB}) \quad \text{(B1-8)}$$

and

$$G = x_A G_A^\circ + x_B G_B^\circ + n\,RT(x_A \ln x_A + x_B \ln x_B) + n\,x_A x_B (N z/2)(2 V_{AB} - V_{AA} - V_{BB}) \quad \text{(B1-9)}$$

Here N is Avogadro's number, z is the coordination number (the number of nearest neighbors of an atom), and V_{AA}, V_{BB}, and V_{AB} denote the (negative) bond energies. The effects of deviations from ideality can now be examined by considering the relative magnitudes of V_{AB}, the unlike pair interaction, with $(V_{AA}+V_{BB})/2$, the average like pair interaction. The error made by assuming a regular solution, or randomness, is not large for small deviations from ideality. By making this assumption both the heat of mixing and the entropy of mixing are overestimated, but these contributions are of opposite sign in the free energy expression. When the solution is far from random Equation B1-9 no longer applies. For example, when $2V_{AB}-(V_{AA}+V_{BB})<0$, intermetallic compounds become stable as intermediate phases. When $2V_{AB}-(V_{AA}+V_{BB})>0$, the system tends to segregate into a two-phase mixture. In neither event can Equation B1-9 be applied.

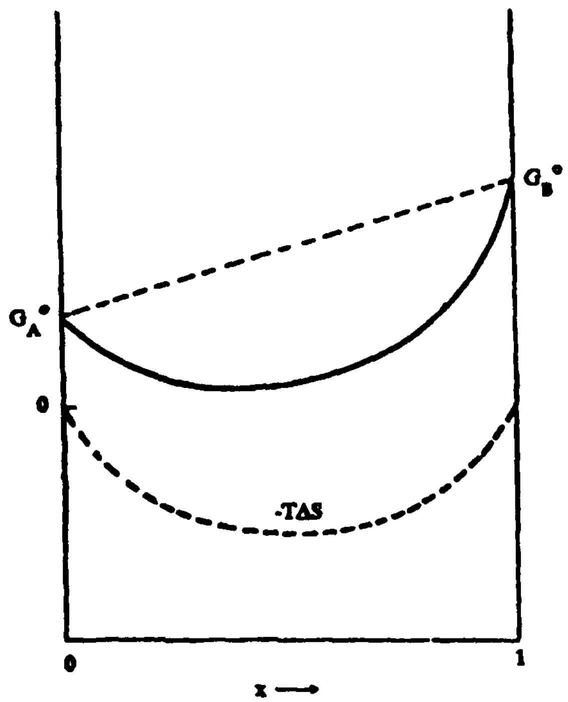

Figure 1. Gibbs free energy versus concentration of an ideal binary alloy. The activities equal the mole fractions. A and B atoms are randomly distributed on the lattice. The upper dashed curve is what the free energy would be were there no mixing. The lower dashed curve is the reduction in free energy because of the entropy of mixing of this ideal solution. The solid curve, the free energy of the solution, is the sum of these.

COMPETING PHASES; ALLOTROPIC (POLYMORPHIC) TRANSFORMATIONS

Suppose element A can exist in either of two phases, α or γ. (Perhaps α is fcc and γ is bcc.) And suppose element B has a range of solid solubility in both phases. The Gibbs free energies of both phases fall with increasing temperature, but it can happen that the free energy of the low temperature phase does not fall as fast, and is overtaken by the other phase as the temperature is increased. For example, a close packed phase such as fcc will tend to have a lower internal energy and will lie lower at low temperature. But as the temperature is raised a more open structure with more entropy such as bcc will shift down (relatively) to a lower free energy. Figure 2 shows the relative positions of the two phases at a series of temperatures. It is convenient to progress from high temperature down. Figure 2 shows that at high temperature T_4 the γ phase has lower free energy at all concentrations. At T_3 the two energies are equal at x=0. (This is possible because of the infinite slope and derivatives at x=0. T_3 is the polymorphic transition temperature for pure A.) At progressively lower temperatures the α phase shifts down (relatively). How does one construct the phase diagram from this progression?

THE LEVER RULE

Figure 2 shows a series of tangents. Consider temperature T_1. x_l and x_r are the concentrations at which the tangent line touches the two G(x) curves. At that temperature, at all concentrations less than x_l the free energy will be least when the entire alloy is in the α phase. And at all concentrations greater than x_r the free energy will be least when the entire alloy is in the γ phase. Suppose the average concentration is between x_l and x_r, at x_{avg}. In this intermediate range the free energy of both phases is everywhere higher than at x_l and x_r; it is minimized by segregating into a mixture of the two phases, of compositions x_l and x_r, respectively. Suppose a fraction f of B atoms segregates in regions of α phase and (1-f) in regions of γ phase. Conservation of the number of B atoms requires that

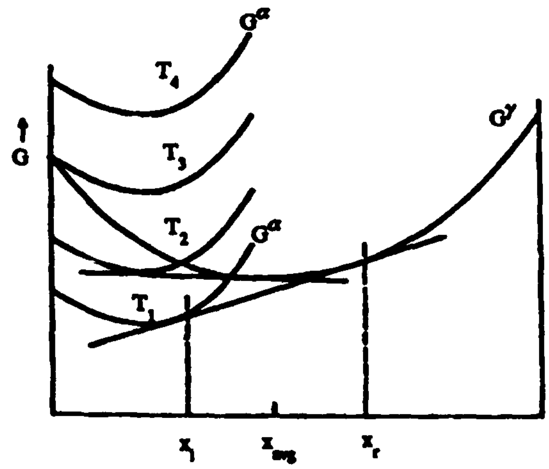

Figure 2. The lever rule. The free energies of two phases, α and γ, are shown at a series of temperatures. Although both free energies rise with decreasing temperature, we assume that G^{α} does not rise as fast as G^{γ}. To simplify the figure G^{γ} is drawn as though it were not changing with temperature and G^{α} is shown relative to G^{γ}. This convention will be followed in figures to follow. At high temperature T_4, G^{α} lies entirely above G^{γ}. At a lower temperature T_3 the two curves first touch, at $x=0$ in the case assumed. Progressively at T_2 and T_1, G^{α} lies below G^{γ} over a range of concentrations extending from $x=0$ up to the crossing of the curves. The figure shows a tangent line touching the two free energy curves at temperature T_1. Concentrations to the left of x_l, the tangent point with G^{α}, are single phase α; those to the right of x_r, the tangent point with G^{γ}, remain single phase γ. Those concentrations such as x_{avg}, between x_l and x_r, partition by diffusion to a two-phase mixture of α and γ. This is the equilibrium mixture of lowest free energy.

$$f x_1 + (1-f) x_r = x_{avg}$$

$$f = \frac{x_n - x_{avg}}{x_n - x_1}; \quad (1-f) = \frac{x_{avg} - x_1}{x_n - x_1} \qquad (1)$$

This is the lever rule.

The Gibbs free energy of the heterogeneous, two-phase solid is

$$G = f\, G^{\alpha}(x_1) + (1-f) G^{\gamma}(x_r) \qquad (2)$$

$$G = \frac{x_n - x_{avg}}{x_n - x_1} G^{\alpha}(x_1) + \frac{x_{avg} - x_1}{x_n - x_1} G^{\gamma}(x_r) \qquad (3)$$

It is important to note that x_l and x_r, the concentrations of the segregated homogeneous regions, depend upon temperature. But at any given temperature the concentrations of these regions do not depend upon the average composition, x_{avg}; only the fractions of the phases in the two kinds of regions depend upon the average composition.

The points of tangency x_l and x_r, shifting with temperature, make up the boundaries between phases in a (temperature, concentration) phase diagram. The diagram corresponding to Figure 2 is shown in Figure 3.

EUTECTOIDS*

Next imagine there to be three phases. At high temperature the free energy of the γ phase again lies lowest at all concentrations.

*At a eutectic point the liquidus--the boundary between liquid and liquid-solid two-phase regions--has a minimum at some concentration. A eutectoid occurs within the solid phase, when the lower temperature boundary between a solid phase and two two-phase regions occurs at minimum temperature at some particular concentration.

The β phase, perhaps hcp, need not overlap the α phase in solid solubility for the following argument to apply, but the ranges of α and β each overlap γ. There are many possibilities; we assume that as the temperature is reduced, G^{α} drops below G^{γ} at a higher temperature than does G^{β} (at a different x). Figure 4 shows the free energy curves for two temperatures and the tangent lines and points of tangency.* It can occur that all the way down to T=0, the α-γ tangent line lies below the G^{β} curve. Or to put it another way, at no temperature do the two tangent lines have the same slope and the two tangency points with the G^{γ} curve merge (reach the same x). In this case the γ field extends all the way down to T=0. This is shown in Figure 5.

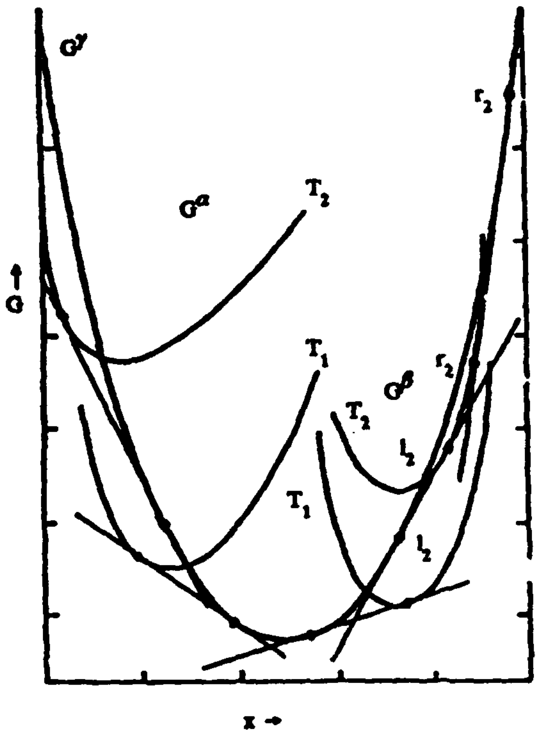

Figure 4. Three G(x) curves. G^{α} and G^{γ} evolve with temperature as in Figure 2. With decreasing temperature, G^{β} is assumed to have first touched G^{γ} at some x<1. This causes a maximum congruent point at that temperature and concentration as shown on the phase diagram (Figure 5). At some lower temperature T_2, there are two tangent lines between G^{β} and G^{γ} with pairs of tangent points l_2 and r_2. The r_2 points define the two boundaries of the mixed ($\beta+\gamma$) field on the extreme right side of Figure 5. The l_2 points determine the boundaries of the more central ($\beta+\gamma$) field in Figure 5. At a still lower temperature T_1 there is only one tangent between G^{β} and G^{γ} and therefore only one ($\beta+\gamma$) field. At T_1 there is also a tangent between G^{α} and G^{γ} that defines the ($\alpha+\gamma$) field.

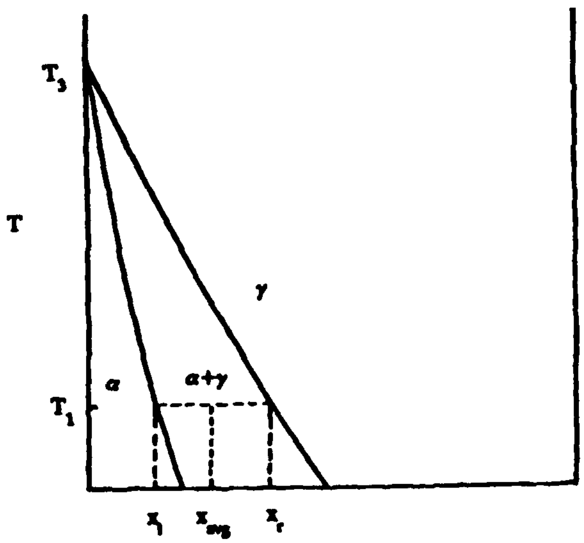

Figure 3. The phase diagram that results from the sequence of free energies depicted in Figure 2.

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*Only to introduce another concept, we depict a situation in which the G^{β} curve first tangents the G^{γ} curve at x<1. This causes a maximum congruent point. In Mg-Li the liquidus and solidus meet at a maximum, at about 30 at. % Li, at 600 °C.

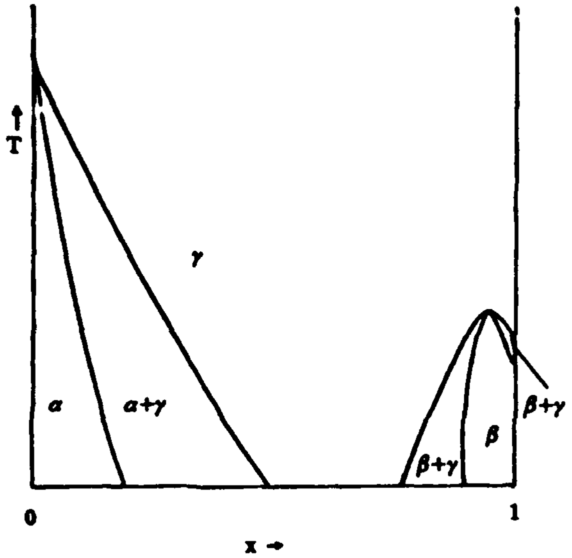


Figure 5. The phase diagram related to Figure 4.

The more interesting situation, with a eutectoid, is illustrated in Figures 6 and 7. At high temperature, T_6, both G^α and G^β lie above G^γ. At T_5, G^α first touches G^γ, and at a still lower temperature T_4, G^β also tangents G^γ (at x=1; we revert to terminal solid solutions at both ends of the diagram). At T_3 both G^α and G^β lie below G^γ over some ranges of concentration. The two tangent lines have different slopes and touch the G^γ curve at different concentrations. At $T_2=T_e$, the eutectoid temperature, the tangency points merge. There is a single common tangent to the three free energy curves. Below T_e, at T_1, the lowest free energy of the solid is attained by mixtures of α and β phases alone; at T_e, in equilibrium, all γ phase converts to α and β. This is depicted in the corresponding phase diagram, Figure 7.

GIBBS PHASE RULE

The usual statement of the Gibbs phase rule is that the number of degrees of freedom, f, equals 2 plus the number of components, c, minus the number of phases, P. But since we have suppressed pressure as a variable--a degree of freedom--in this reduced space

$$f = 1 + c - P \tag{4}$$

Phase diagrams and the phase rule merit contemplation. In Figure 7, the three single-phase fields of the terminal solid solutions are simply understood: two components, one phase: two degrees of freedom (T and x). Within any of the two-phase fields there is one degree of freedom. At any T there are particular concentrations in each of the two phases. For example, in Figure 7 at temperature T_1 all the α phase has atomic fraction x_l and all the β phase has concentration x_r. (But the two phases are mixed in arbitrary amounts in the heterogeneous solid, depending upon the average composition x_{avg}.) The eutectoid line is special. It borders three phases, and so there are no degrees of freedom. The temperature is fixed, T_e, and the concentrations in the α and β phases are also fixed.

NONEQUILIBRIUM; AN EXAMPLE

Suppose a homogeneous alloy is in the γ phase at a temperature well above T_e, and at a composition x_a, indicated in Figure 7 as point a. There are no complications on cooling down to point b on the phase boundary, but between points b and c equilibrium requires the formation of α phase particles rich in element A dispersed in a matrix of γ phase richer in element B. This process occurs by interdiffusion of A and B atoms between the γ matrix and the α particles. Diffusion may not be rapid enough to reach equilibrium. As cooling continues the particles can grow in a cored state, A-rich at the center and with a decreasing concentration of A extending to the α-γ interface. The γ matrix surrounding each particle will also have compositional gradients.

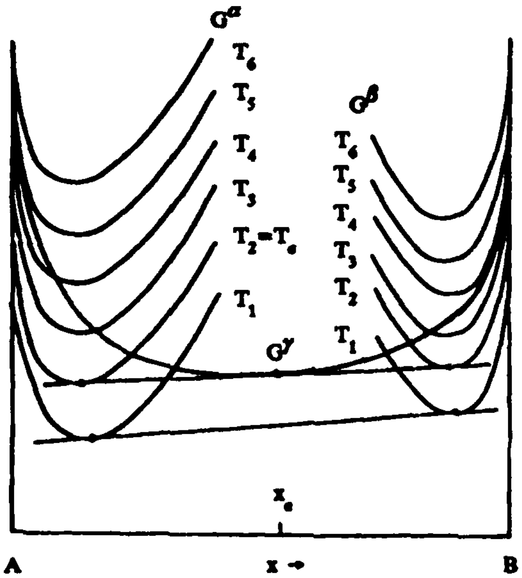


Figure 6. Thermal evolution of three free energy curves, again drawn relative to G^γ, the high temperature phase. With decreasing temperature first G^α (at T_5 and at $x=0$) and then G^β (at T_4 and at $x=1$) meet and fall below G^γ. At temperature $T_2=T_e$, the eutectoid temperature, the two tangent points with G^γ meet (at x_e, the eutectoid composition). Below this temperature γ phase is no longer present in equilibrium.

NONEQUILIBRIUM; ANOTHER EXAMPLE

Suppose, again referring to Figure 7, one starts with the alloy in the γ phase at point a. Suppose that by cooling sufficiently slowly one is able to approach in equilibrium the eutectoid temperature, point c. Just above T_e the solid is a mixture of α and of γ, and the γ phase material is of concentration x_e. On cooling below T_e, γ transforms to a mixture of α and β. On the figure we have drawn the extension lines of the equilibrium phase boundaries between α and γ--the boundaries that would have prevailed had there been no β phase--and similarly for β and γ. It can happen that the formation of β phase is suppressed; we shall give a mechanism next. It then occurs that for some continued decrease of temperature below T_e the system exists in metastable quasi-equilibrium, a mixture of α and γ phases described by the lever rule applied to the α-γ phase boundaries, the dashed lines. Such metastability can also occur at the eutectoid composition x_e, and the metastable phases which are formed depend upon factors controlling the nucleation of the α and β phases.

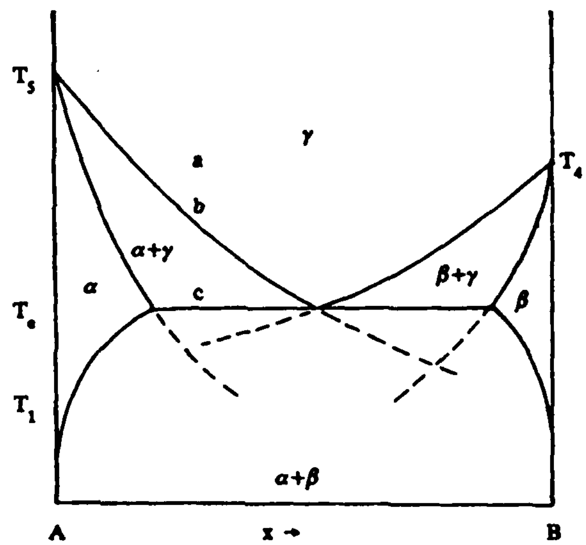


Figure 7. Phase diagram related to Figure 6. The diagram also shows, as dashed lines, the nonequilibrium extensions of the two-phase boundaries. These are what the phase diagram would have been had formation of the third phase been suppressed.

SURFACE FREE ENERGY; GRAIN GROWTH

It often happens that one phase originates in another in a finely divided state, with an energy barrier inhibiting precipitate formation. The physics can be described by a phenomenological (positive) surface energy per unit area of interface, σ. This energy density will be specific to the two phases and components (and concentrations) but will equally inhibit the formation of α in β, say, as of β in α.

Assume spherical grains of stable radius r. V_o is the molar volume of β, the precipitating phase, of which n moles precipitate: $V=V_o n$. Suppose p particles precipitate. The area of precipitate is $A=p4\pi r^2$. The number of moles of precipitate is $n=p4\pi r^3/3V_o$. The increase in Gibbs free energy of the finely dispersed phase is:

$$\Delta G_n = \frac{\partial G}{\partial A}\frac{\partial A}{\partial r}\frac{\partial r}{\partial n}\Delta n$$

$$\Delta G_n = \frac{c\,\sigma\,V_o\,n}{r} \qquad (5)$$

c is a constant of order unity, depending upon the average shape of the small grains. For spherical grains c=2. Equation 5 is a form of the Gibbs-Thomson equation.

Suppose this to be the case for the β phase in Figure 8. The shifted $G^\beta+\Delta G_n^\beta$ curve will now tangent G^γ at a temperature below T_e. Meanwhile G^α has been falling relative to G^γ. Thus the α and γ fields follow the metastable boundaries, the dashed extensions shown in Figure 8. Finally at some suppressed supercooling temperature, T_1', the β grains grow. However, the solubility of the fine particles of β in α is higher than the solubility of large pieces of β, as shown in Figure 8. Furthermore, the eutectoid temperature will be lower for fine particles. After the sample is held a sufficiently long time at temperature T_1', as grains become large, ΔG_n^β goes to zero and the solubility of B in α increases accordingly. Similar effects can occur if the new phase being formed is highly stressed by coherence with the matrix. The free energy can be considered to be increased by some amount ΔG by the elastic energy accompanying coherence.

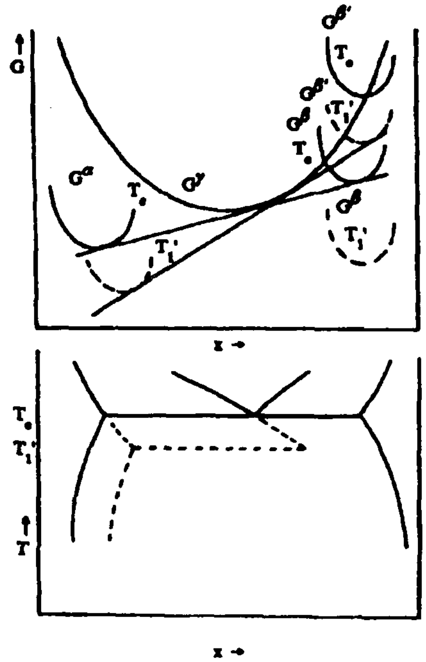


Figure 8. Upper diagram. The effect of an energy shift on the free energy curves and phase diagram. Free energy curves of three phases, α, β, and γ, are shown. Temperature T_e would be the eutectoid temperature. But the energy of β is raised by amount ΔG^β, perhaps by interface energy or strain. For there to be a common tangent to the α, γ, and shifted β' curves, the system must be undercooled to temperature T_1'. Free energy curves at temperature T_e are drawn solid; those at T_1' are drawn dashed. The lower diagram shows the phase diagram. The metastable eutectoid temperature is lowered and the eutectoid composition is shifted to a higher concentration of B. Since we have considered precipitation of β in α, but not of α in β, the diagram is drawn only for compositions less than the eutectoid concentration.

The separation of the free energy into a G for the true equilibrium state and a ΔG arising from interfacial energy and/or stress, and of an "intrinsic" transition temperature and supercooling and superheating shifts from it because of ΔGs, may seem arbitrary. But the separation is a useful one, particularly when the ΔGs are ephemeral. The competing reactions and factors influencing nucleation can be examined and compared.

UNDERCOOLING OF LIQUIDS: NUCLEATION

In discussing nucleation we will use the liquid to solid transformation as an example, but the approach is also applicable to other transformations. The important concept is that the free energy expression for nucleation contains a term for the difference in free energy of the two phases (at the temperature at which the transformation actually occurs) plus other terms depending upon interactions between the nuclei and the host matrix. Such interactions can include interfacial energy and, in the case of solid-solid transformations, elastic strain energy. Beyond the temperature at which the volume free energies of the two phases participating in the reaction are equal, this volume free energy term for the transformation is negative, but at least one of the other terms is positive and compensating. The volume free energy change for the transformation becomes larger, the larger the temperature increment beyond the transformation temperature (i.e., the temperature at which the transformation would have occurred had there been no interfacial, elastic, or other energy terms), but the other terms are not dependent upon ΔT. Consequently, nuclei form after a ΔT is reached for which the transformation lowers the free energy enough to compensate for any free energy increases produced by the nuclei-matrix interactions.

Because of interfacial energy, precipitation of the solid phase from the liquid does not occur until the liquid is undercooled sufficiently to compensate for the increased interfacial energy. However, in view of Equation 5, the interfacial energy depends on the size of the solid nuclei. The free energy change (ΔG_{hom}) on forming a solid spherical nucleus of radius r is

$$\Delta G_{hom} = \frac{4}{3}\pi r^3\left(\frac{G_s - G_l}{n V_o}\right) + \frac{3 n V_o \sigma}{r} \qquad \ldots\ldots\ldots (6)$$

Below the melting point (the transformation temperature), ΔG_v ($=G_s$-G_l) is negative but the interfacial term is positive. For a specific amount of undercooling, ΔT, there will be a critical radius r* for radii greater than which ΔG_{hom} decreases as the precipitate grows. This is ΔG_{hom}*, the free energy barrier to formation of precipitate particles. Box 2 shows the relationship between the surface interfacial energy and the stable radius of the precipitate and presents an equation for the stable nucleation rate.

THE STEP RULE: NUCLEATION OF METASTABLE PHASES FROM UNDERCOOLED LIQUIDS

Now we are in a position to return to the Ostwald (Ref 2) idea of passing through a metastable phase in relaxing to equilibrium. We remarked that Turnbull (Ref 1) described a "similar entropy" criterion for favored transformations in structural evolution. **Ishihara, Maeda, and Shingu** (Ref 5) give a quantitative rationale for the step rule for nucleation from an undercooled liquid. We reproduce their argument. A metastable phase competes with the stable phase. Each requires its own fluctuation ΔG^* to nucleate. Since diffusion is through the same medium, the liquid, for the two competing phases, we can suppose that both have the same K. We have suppressed a factor that allows for description of nucleation on surfaces, but we can imagine it to be not too different in the two cases, or restrict consideration to homogeneous nucleation. The phase that will win out will be that of greater nucleation frequency. This will be the phase of smaller critical fluctuation ΔG^*, the barrier to nucleation. Equation B2-6 relates ΔG^* to the surface energy density. Ishihara et al. then relate the surface free energy to the molar latent heat of melting, L, empirically (Ref 1,6):

Box 2. Undercooling: Nucleus Critical Size; Free Energy Barrier for Nucleation

Again suppose that p spherical particles precipitate in the entire sample (we have maintained the physics convention of an extensive Gibbs free energy), each of radius r. The number of moles is n and V_o is the molar volume, as before. The surface energy per unit area is σ, and the difference between solid and liquid free energies at temperature T is ΔG_v. The free energy change is

$$\Delta G_{hom} = p(4 \pi r^3/3)\, \Delta G_v/n\, V_o + p(4 \pi r^2)\, \sigma \qquad \text{(B2-1)}$$

Minimizing ΔG_{hom} with respect to the particle radius, the critical nucleus size is

$$r^* = -2\, \sigma\, n\, V_o/\Delta G_v \qquad \text{(B2-2)}$$

Substituting this in B2-1 gives the free energy fluctuation required to nucleate a particle:

$$\Delta G_{hom}^*/p = (16\, \pi/3)\, \sigma^3\, n^2\, V_o^2/(\Delta G_v)^2 \qquad \text{(B2-3)}$$

The volume Gibbs free energy difference ΔG_v is reasonably approximated by

$$\Delta G_v = \Delta H - T\, \Delta S \simeq -n\, L + n\, T\, L/T_m = -n\, L(T_m - T)/T_m \qquad \text{(B2-4)}$$

where L is the latent heat, T_m is the melting temperature, and T is the actual temperature, the temperature of undercooling. (The minus sign arises from the definition of ΔG_v as G_{sol}-G_{liq}.) Substitution of Equation B2-4 into Equations B2-2 and B2-3 yields

$$r^* = 2\, \sigma\, V_o\, T_m/L(T_m - T) \qquad \text{(B2-5)}$$

and

$$\Delta G_{hom}^*/p = (16\, \pi/3)\, \sigma^3\, V_o^2\, T_m^2/L^2(T_m - T)^2 \qquad \text{(B2-6)}$$

Box 2. Continued

The stable radius r* becomes smaller as the amount of undercooling is increased. Moreover, the free energy fluctuation necessary to form this critical sized nucleus becomes smaller. At a fixed temperature particles of radius less than r* created by statistical fluctuations are unstable; they increase the free energy. They are reabsorbed. A fluctuation in free energy must be as large as $\Delta G^*/p$ to create a particle whose free energy decreases as it continues to grow.

These expressions are for homogeneous nucleation, within the volume of the liquid, with no impurity nucleation sites. When nucleation is on a surface the value of r*, the radius of curvature, is not changed but $\Delta G_{hom}^*/p$ is decreased by an amount determined by the contact angle between the surface and the solid nucleus. Hence the free energy fluctuation required for heterogeneous nucleation of a particle of radius of curvature r* is less than that necessary for homogeneous nucleation. In classical nucleation theory (Ref 1), the homogeneous nucleation rate I is given by

$$I = K \exp(-\Delta G_{hom}^*/n\,RT) \qquad (B2\text{-}7)$$

where K is a temperature dependent kinetic factor that describes the jump frequency of an atom next to the growing nucleus. From Equation B2-6 $\Delta G_{hom}^*/T$ is minimum at $T=T_m/3$ (found by setting the temperature derivative equal to zero). This is the temperature at which the exponential is a maximum. But K decreases with decreasing temperature. As a result the nucleation rate is a maximum at some intermediate temperature below T_m (and in practice usually above room temperature).

$$\sigma = 0.065\ L\ V_o^{-2/3} \qquad (7)$$

Substituting Equation 7 into B2-6:

$$\Delta G^* = 0.0015\ Ln\ T_m^2/(T_m - T)^2 \qquad (8)$$

The critical temperature, when the nucleation frequency of the metastable phase is equal to that of the stable phase, is the temperature at which

$$\Delta G^{*\prime} = \Delta G^* \qquad (9)$$

The prime refers to the metastable phase. Its latent heat and melting temperature are also labelled by primes.

$$\text{Let } A = T_m'/T_m;\ B = L'/L \qquad (10)$$

T_m' is less than T_m and $A<1$. Since ΔG for the metastable phase is less than that for the stable phase it can also be assumed $B<1$, the circumstance under which Equation 9 has a physically significant solution. The temperature at which the two free energies are equal is

$$T_c = T_m\ A(1-B^{1/2})/(1-B^{1/2}\ A) \qquad (11)$$

The critical temperature T_c is between T_m' and 0 K. The nucleation rate of the metastable phase is larger than that of the stable phase when the temperature is below T_c, and the more the undercooling below T_c the larger the difference between these nucleation frequencies becomes. Ishihara et al. compare published experimental crystallization temperatures of metastable phases of

Ga, Bi, and InBi with critical temperatures calculated by Equation 11. In the three cases the two temperatures are in good agreement.

Ostwald enunciated the step rule in 1897. Empirical evidence has supported its preponderant validity. The Ishihara argument, albeit semi-empirical, provides insight into the kinetics that underlie the 90-year-old step rule.

MASSIVE TRANSFORMATIONS

Yet another form of metastability in alloys is associated with those diffusionless transformations termed "massive" (Ref 7,8)--transformations from one crystal structure to another with the same composition. The name, somewhat misleading because it refers precisely to those situations where there is no mass movement, comes from the characteristically bulky or massive shape of the precipitates it causes, as opposed to the needlelike precipitates that grow in the two-phase separation that competes with it. The process is exemplified in the Cu-Zn and the Cu-Ga systems (Ref 8,9). Figure 9 is the Cu-Zn (brass) phase diagram, and Figure 10 is an enlarged portion of it, stretched to aid the eye. The α phase, fcc, is the terminal phase based on the Cu lattice structure; β is a disordered bcc intermediate phase (β' is bcc with the Cu and Zn ions ordered). We shall be concerned only with the α and β phases. Their concentration ranges overlap. At 902 °C the β phase extends down to about 36 at. % Zn, and at 454 °C the α phase extends up to over 38 at. % Zn. We want to compare the free energy change for the massive transformation, β to α of the same composition, with that for partitioning to a mixture of α and β of different concentrations, and we want to compare these energy changes at different temperatures. Consider an alloy with, say, x=0.37 and at a temperature of 900 °C or a bit below. This is point a on Figure 10. Figure 11 shows the relative Gibbs free energy of the two phases in the concentration range of interest and at significant temperatures, the points on Figure 10. Clearly, at 900°, $G^{\alpha}(0.37) > G^{\beta}(0.37)$, since β is stable. (We are leaving out nucleation energies now.) The tangent points at 900 °C on Figure 11 show the concentration limits of the two-phase region at this temperature and, of course, the composition x=0.37 is not included because at this composition β is stable. The alloy remains single phase down to 850 °C, point b on Figure 10. At this temperature the tangent line touches G^{β} at x=0.37 (Figure 11). Cooling further (and slowly enough so as to remain in thermodynamic equilibrium--a difficult process and perhaps unachievable, since α of continuously varying concentration deposits out, and diffusion of Zn into and/or Cu out of these deposits is required to remain in equilibrium), Widmanstätten needles or plates precipitate out, depending upon the cooling rate. The significance of point c (Figure 10), within the two-phase region, is that at this temperature (750 °C) and concentration (x=0.37) $G^{\alpha}=G^{\beta}$ (but a mixture of the two with concentrations x=0.35 and x=0.38 (roughly) lies lowest). d is the lower edge of the two-phase region at x=0.37. At this temperature, perhaps 550 °C, the tangent to G^{α} is at x=0.37 (see Figure 11).

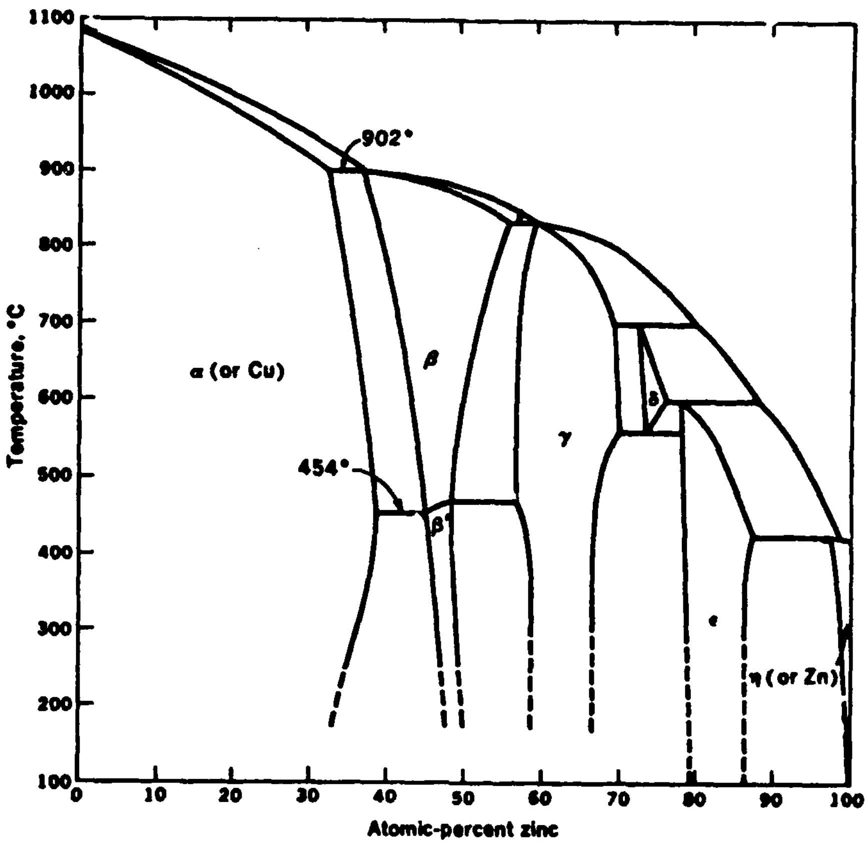


Figure 9. Cu-Zn phase diagram. M. Hansen and K. Anderko, *Constitution of Binary Alloys*, 2nd ed. (McGraw-Hill Book Company, New York, 1958). Reproduced with permission.

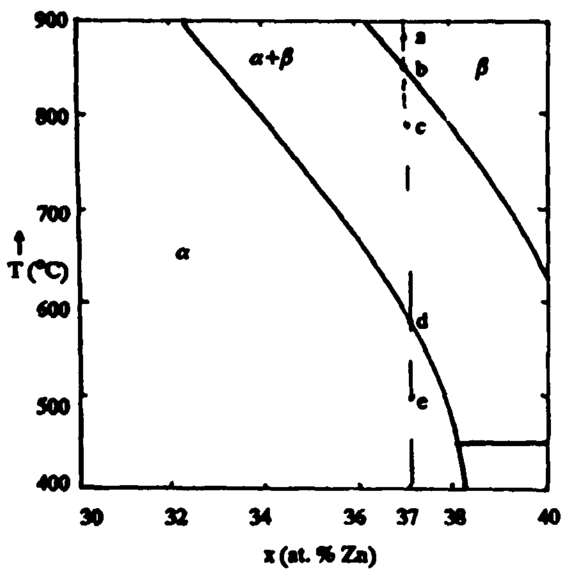


Figure 10. An enlarged portion of the Cu-Zn phase diagram of Figure 9. The points a-e are significant temperatures discussed in the text, in the massive transformation that occurs upon rapidly cooling an alloy of composition x=0.37 at. % Zn.

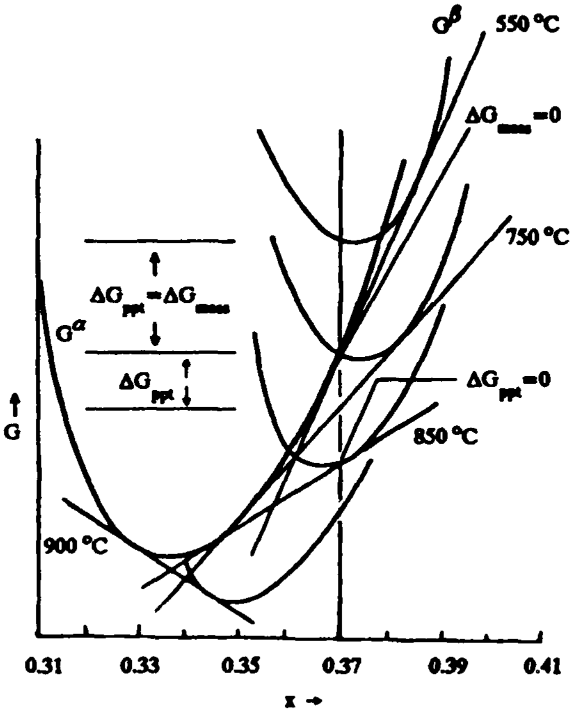


Figure 11. Free energy curves for the α and β phases at the temperatures indicated by the points a-d in Figure 10. The quantities ΔG_{ppt} are free energy changes for β to transform to a mixture of α and β. At 850 °C, at x=0.37, $\Delta G_{ppt}=0$. The quantity ΔG_{mass} is the difference in free energy between the β and α phases. At 750 °C, at x=0.37, $\Delta G_{mass}=0$ (the free energy curves cross). At 550 °C, at x=0.37, $\Delta G_{ppt}=\Delta G_{mass}$.

Free energy changes in the two processes can now be compared. These are plotted in Figure 12. ΔG_{ppt} is the free energy difference between the two-phase and pure β states--how much the tangent line is below G^{β} at x=0.37. Above 850 °C β is stable and hence ΔG_{ppt} is positive and the precipitation process can be considered to be unphysical (see Figure 11). As the temperature is reduced this quantity grows more negative. Below d, the lower bound of the two-phase region for x=0.37, it is again an unphysical process. The free energy change of the massive transformation [$G^{\alpha}(0.37) - G^{\beta}(0.37) = \Delta G_{mass}$] is also plotted versus temperature in Figure 12. It can be seen that ΔG_{mass} becomes more negative than ΔG_{ppt} at 500 °C and below. Consequently, if an alloy at composition 37 at. % Zn is rapidly cooled from 900 to 500 °C or lower, β will massively transform to α.

The precipitation process requires mass diffusion to segregate into regions of different concentrations. This minimizes the free energy, in the two-phase region, but requires time. The massive transformation is a diffusionless process and the alloy remains homogeneous. Consequently, with sufficiently rapid quenches it is possible to prevent the precipitation process in the two-phase region and have the massive transformation occur.

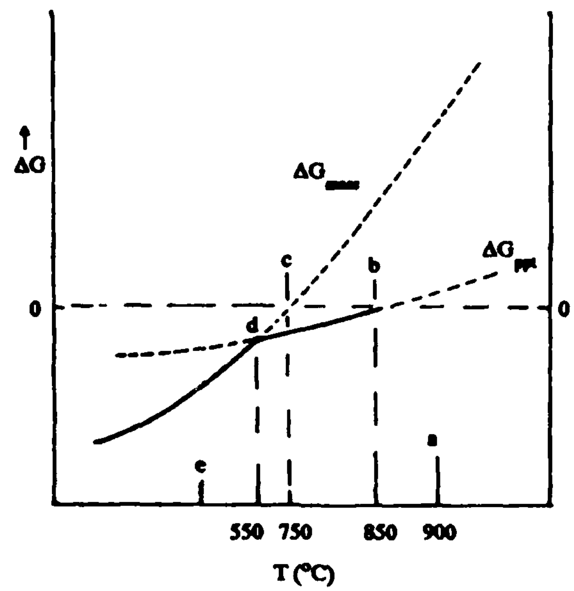


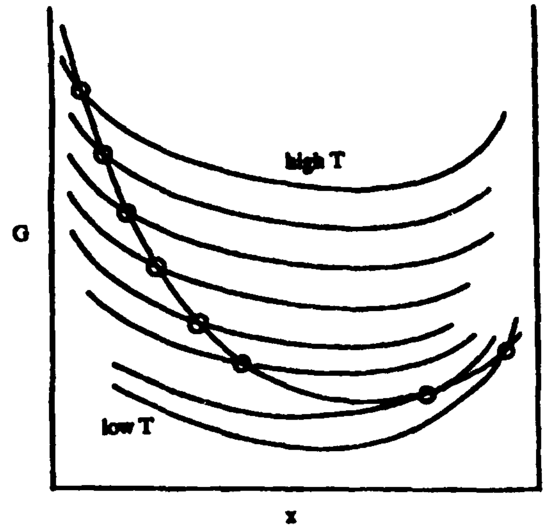
Figure 12. Comparison of the free energy changes for β transforming to the equilibrium mixture of α and β, ΔG_{ppt}, and for β transforming massively to α, ΔG_{mass}.

One may ask, what is all the fuss about? What has been gained? The reality is something different from the idealization. The texture of the quenched, massively transformed alloy is in fact very different from that which is slowly cooled. Neither process is in fact fully realized. The slowly cooled ingot is not in equilibrium. Cu-rich fcc α precipitates form colonies of Widmanstätten needles in the bcc β matrix. Even with long annealing some of this texture is likely to remain. With rapid quench and massive transformation the alloy is more homogeneous, and the compositional fluctuations are more granular, less acicular. To the metallurgist those differences are very important. They are reflected in the mechanical properties, electrical conductivity, sound absorption, and corrosion resistance.

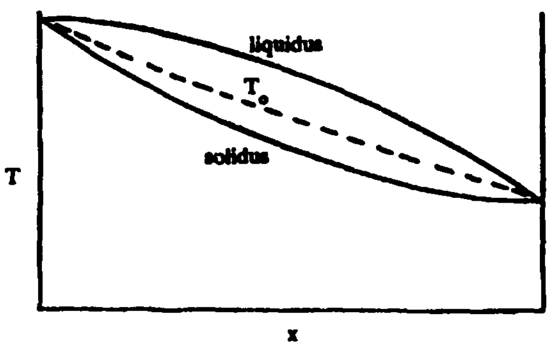
T_0 CURVES; METASTABLE PHASE DIAGRAMS

A great deal of Japanese (and worldwide) research on metastable phases involves massive transformations. These diffusionless transformations can occur, for example, in rapid solidification, ion beam mixing and laser melting, vapor deposition, and solid state reactions. A concept that aids in understanding massive transformations is known by metallurgists as the T_0 curve. We are now well prepared to understand it from the discussion of Figure 11. The tangent points on that figure are the concentration boundaries of the two-phase regions at those temperatures. At each temperature there is a concentration at which the free energy curves for the two phases are equal (and cross). One of these is at 750 °C and x=0.37. The T_0 curve is the locus of those crossing points.

Let us plot and discuss the significance of T_0 for a simpler phase diagram. On Figure 13a we show Gibbs free energy curves for a solid phase, with full solid solubility from pure A to pure B, relative to that for the liquid, at a series of temperatures. One set of tangent points gives the liquidus of Figure 13b, the other the solidus. The locus of encircled points, the crossings, is the dashed T_0 curve of Figure 13b. We have seen that if we cool quickly from above the liquidus to below the solidus, the alloy can be kept homogeneous (or almost so). This is the noncooperative, diffusionless, massive transformation. ("Noncooperative" to distinguish this single-particle transformation from a martensitic-type transformation, which is also diffusionless but is long range ordered and cooperative, a simultaneous sheer of the entire lattice. Metallurgists refer to noncooperative transformations as "civilian" and cooperative ones as "military.") At any composition in Figure 13b, at temperatures above T_0 the liquid phase has lower free energy; at temperatures below T_0 the solid phase has lower energy. Thus, in rapid cooling through the massive transformation the equilibrium two-phase region can be viewed as collapsing to a line. $T_0(x)$ is the liquidus-solidus phase boundary. The material would be liquid above T_0 and solid below if there were no nucleation energies, the ΔGs previously discussed. (But quenching must start at or above the equilibrium liquidus and carried to or well below the equilibrium solidus; if the temperature is held long enough at T_0, or at the supercooled temperature at which nucleation actually occurs, diffusion may allow some reliquefication and segregation to the lower free energy two-phase mixture.)



(a) Free energy curves for a solid relative to that for a liquid, as a function of temperature.



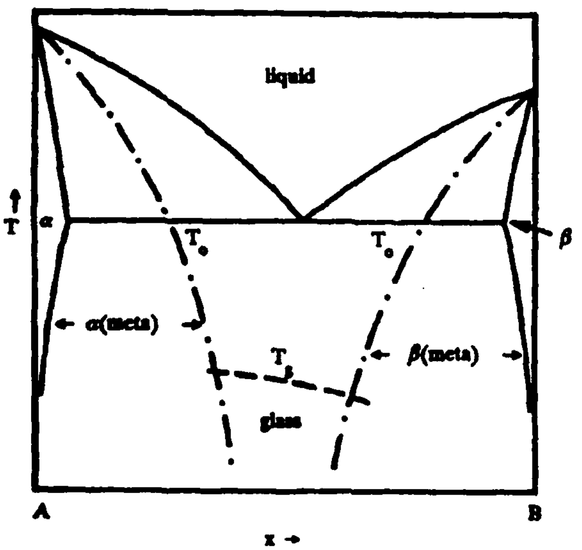
(b) Phase diagram. The encircled points in (a) are temperatures and concentrations at which $G_{liq} = G_{sol}$. The locus of these points is the T_o curve shown in (b).

Figure 13. The T_o curve.

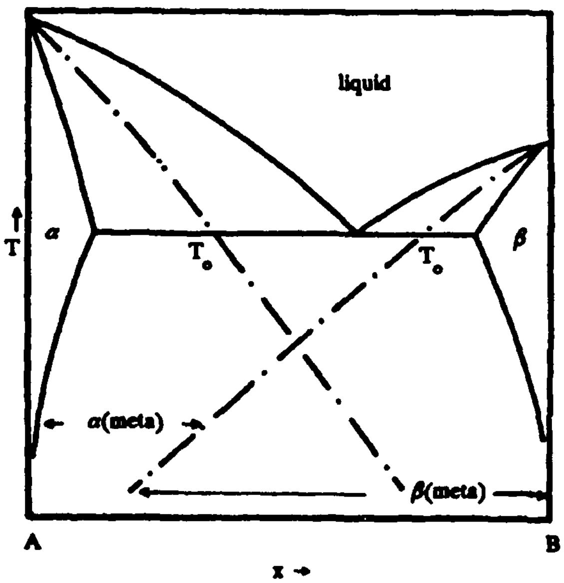
We have presented the T_o line in the context of rapid quenching from the melt. The same considerations apply to other regions of the phase diagram. A solid material, cooled rapidly enough to remain homogeneous, from above to below a two-phase region, transforms from the high temperature to the low temperature phase at some supercooled temperature (depending upon the ΔG of the nucleation process) below T_o (for that concentration).

T_o curves are highly suggestive of what metastable phases are possible of attainment, and much has been written about them, particularly by Perepezko and Boettinger (Ref 10). Figure 14, from those authors, illustrates two schematic eutectic phase diagrams. Case a, in which a gap remains down to the lowest temperatures between the two T_o curves, is a good candidate for amorphization. The α and β regions can be extended metastably; in the region to the left and below the left T_o curve, α can be formed by rapid solidification of the liquid, similarly for β phase to the right of the right T_o curve. But in the central region neither α nor β of that concentration can be formed. This can allow rapid cooling to below the glass temperature, T_g, without crystallization. In case b, in which the T_o curves cross, rapid solidification in the central region to below the T_o curves will yield α or β or some mixture of them (depending up[illegible]tics), both with the concentration of t[illegible]nal liquid.

Numerous investigators employing a wide variety of preparation techniques have used T_o curves on phase diagrams such as Figure 14 to account for the formation of amorphous or crystalline phases. Preparation techniques have included not only rapid solidification but vapor phase quenching and the energetic mixing of powders of small particle size.



(a) T_o curves with a gap. The ranges of solid solubility of A in α and of B in β can perhaps be extended metastably out to the T_o lines, but solubility of A in α or of B in β is energetically unfavorable in the central range of compositions. At compositions between the T_o lines such a system is a likely candidate for amorphous phase formation below the glass temperature.



(b) Crossing T_o curves. Ranges of metastable solid solubility overlap (after J.H. Perepezko and W.J. Boettinger, Ref 10).

Figure 14. Phase diagrams for two liquid-to-crystal transformations with eutectics.

NONEQUILIBRIUM SOLID SOLUTION FORMATION OF (III-V)-IV SEMICONDUCTORS

Ishihara, Shingu, Matsueda, and Furuhata (Ref 11) have prepared crystalline solid solutions of three pseudo-binaries, InSb-Ge, AlSb-Ge, and GaSb-Ge, by rapid quenching of the liquid alloys. In the InSb case, a solid solution was formed in a narrow range only on the InSb side--it was not possible to freeze the massive transformation at the Ge-rich end. In the AlSb case the metastable unpartitioned solid was formed in a range on the Ge edge. For GaSb-Ge a solid solution is obtained over the entire concentration range. The authors estimate the T_o curves by a thermodynamic argument. The significant conclusion is that the T_o curves are shallow. This suggests that solid solutions should be formed, as is observed, especially in the range on the low melting side up to the eutectic.

AMORPHIZATION OF BORON-IRON SYSTEM BY ION IRRADIATION

By electron beam deposition, **Sakamoto** et al. (Ref 12) deposit 50- to 100-nm-thick boron films on iron substrates. The films, at room temperature, are then bombarded with 400 keV Xe^+ ions. The physical and magnetic properties of the films are then studied by x-ray and Mossbauer spectroscopy. In the 100-nm films, x-ray diffraction shows an ion-induced ferromagnetic phase that is amorphous. Increasing the flux increases the amount of mixed B-Fe, but this later partially recrystallizes. Hyperfine field measurements show three envelopes, separately encompassing the FeB, Fe_2B, and Fe_3B hyperfine fields. Sakamoto et al. point out that only the FeB recrystallizes; Fe_2B and Fe_3B remain amorphous.

Fe_3B is in the compositional neighborhood of a deep eutectic in the phase diagram, where it is easier to form the amorphous phase by liquid quench (see Figure 14a), and FeB is far from that composition, in an extended solid-solubility regime. Independently, Nakajima et al. (Ref 13) report efforts to form amorphous B-Fe at various concentrations by rapid solidification. Their conclusion, that amorphous boron iron can be produced by liquid quench only for concentrations of less than 35 percent B, is consistent with the observations of Sakamoto et al. Mogro-Campero et al. (Ref 14) have also reported a crystalline-to-amorphous transition in Fe_3B, but with electron irradiation.

ELECTRON IRRADIATION-INDUCED AMORPHIZATION IN INTERMETALLIC COMPOUNDS

The evidence from Sakamoto and from Nakajima on the Fe-B system, fitting in with much other evidence of amorphization in regions of plunging and nonoverlapping T_o curves, can be extended to other intermetallic compounds as well. By irradiating with very high energy (2 MeV) electrons, H. Mori and coworkers have attempted to induce crystalline-to-amorphous transitions in many intermetallic compounds (Ref 15-17). Most recently (Ref 17) they report on 40 intermetallic compounds in Al-transition metal series; Al with Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zr, Mo, W, and Au. They look for a unifying theme among the successes and failures in this large effort and report that "the compounds which can be made amorphous .... are all situated in the composition range over which the liquidus forms a deep valley in the diagram." Two examples are striking. Figure 15 is from the work of Mori and Fujita on the Al-V and Al-Cr systems (Ref 17). In the aluminum-vanadium system there are five intermediate equilibrium phases, $Al_{10}V$, $Al_{45}V_7$, $Al_{23}V_4$, Al_3V, and Al_8V_5. As the figure shows, only the first three, near the deeply plunging liquidus, can be rendered amorphous by electron bombardment or by liquid quench (Ref 18); the other two intermetallic compounds remain crystalline. The same pattern holds in the Al-Cr system. Here there are six intermetallic compounds, Al_7Cr, Al_5Cr, Al_4Cr, Al_9Cr_4, Al_8Cr_5, and $AlCr_2$. Again the composition ranges over which intermetallic compounds can be made amorphous by liquid quench (Ref 19), vapor phase quench (Ref 20), and electron irradiation (Ref 17) coincide, and they cover only those first three intermetallic compounds, Al_7Cr, Al_5Cr, and Al_4Cr, near the deep valley of the liquidus. We would choose to interpret this as being outside the T_o range for which a metastable crystalline solid solution can be extended by analogy with the glass region of Figure 14a.

VAPOR QUENCHING OF IRON ALLOYS

Vapor phase deposition allows the creation of new metastable structures--superlattices, amorphous alloys, complete solid solubility where none exists by other means--that seem almost to transcend thermodynamic constraints. In vapor quenching the gas, either well-mixed or in separate bursts of pure components as one wishes (in creating superlattices), is condensed directly to the solid, skipping over the liquid phase. Of the several methods of vapor deposition, sputtering is especially powerful because the sputtered atoms have kinetic energies of the order of electron volts, ten times the thermal energy of an evaporated atom. It is as though deposited atoms are cooled from

20,000 K instead of 2,000 K, and so the cooling rate is ten times as fast. The examples presented thus far to illustrate behavior consistent with the "T_0 gap" and "plunging T_0" pictures of Figures 14a and 14b and 15 involved rapid quenching from the melt and amorphization by ion and by electron bombardment for which the excitation energies were relatively small compared to those imparted in sputtering, and in no instance were sublimation and condensation--gas to solid--considered.

Nakamura and coworkers have exploited sputtering onto room temperature and cold substrates to produce metastable iron alloys, binary and ternary (Ref 21). Iron forms no equilibrium solid solutions with Ag and Cu, and Fe and Ag are immiscible even in the liquid state at 2,300 K. But when sputter-deposited onto water-cooled substrates, solid solutions or mixtures of two solid solutions are formed over the entire concentration range for both alloy systems. The metastable phases so produced are a bcc phase in the Fe-rich region, an fcc phase in the Ag- or Cu-rich region, and a mixture of bcc and fcc in-between. With the ternary alloys of Fe-Ag-Cu in the central region of the concentration triangle, deposition onto water-cooled substrates produces polycrystals, but deposition on liquid-nitrogen-cooled substrates yields amorphous alloys. Variation of the Ar gas pressure also affects the structure produced.

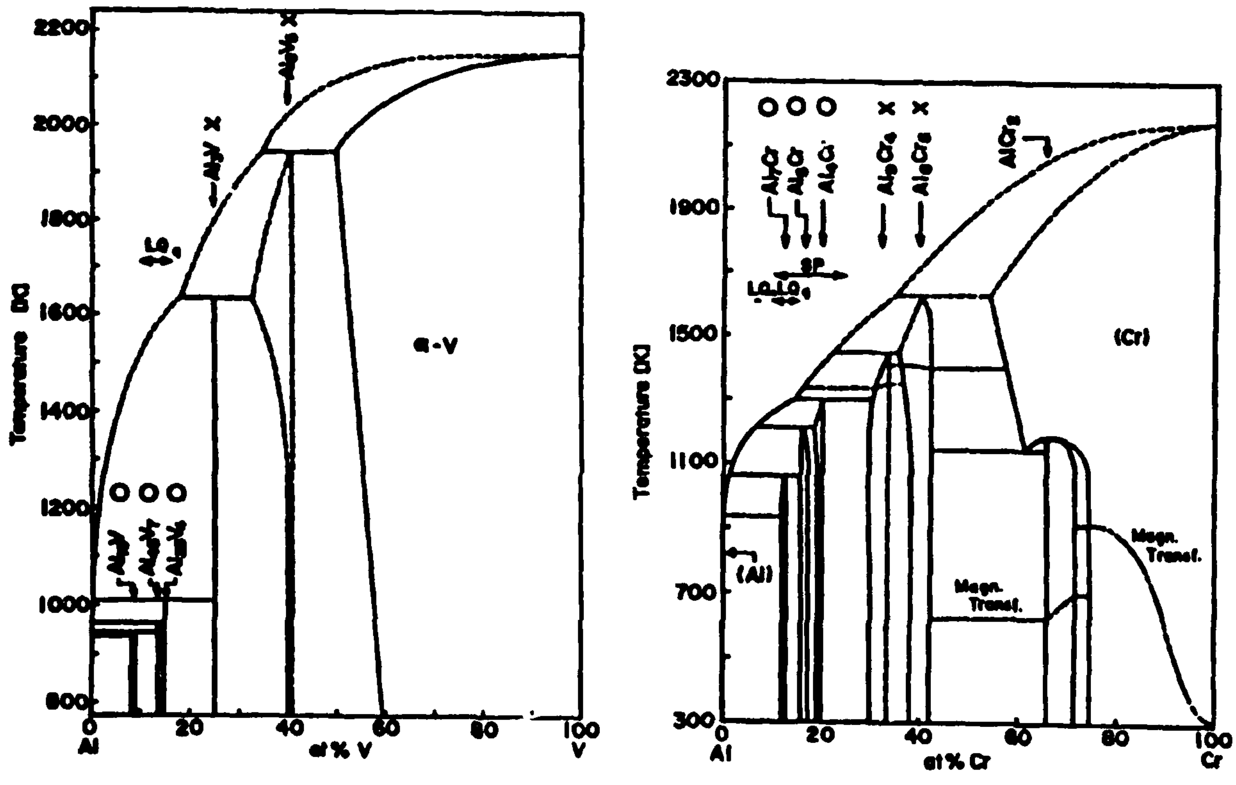


Figure 15. Phase diagrams for the Al-V and Al-Cr systems. M. Hansen and K. Anderko, *Constitution of Binary Alloys*, 2nd ed. (McGraw-Hill Book Company, New York, 1958). Reproduced with permission. Those intermetallic compounds whose compositions lie close to the deep valley in the liquidus can be made amorphous by electron irradiation; those compounds at whose composition the slope of the liquidus is relatively flat remain crystalline under bombardment (Ref 17).

Spanning the concentration range where, in equilibrium, Fe-Ti exists as the intermetallic compounds Fe_2Ti and FeTi, sputtering onto a room temperature substrate produces an amorphous structure.

Can we rationalize all of this on the basis of the T_0 curve theme presented so far? Not entirely. Perhaps sputtering, with its large energy and (perhaps) not fully controlled effective surface temperature, requires some new concepts and subdivisions. Some of Nakamura's findings fit well with the simple model. Nakamura reports that in Fe-Ag and Fe-Cu the metastable bcc and fcc terminal solid solutions extend from both borders well out into the diagrams--out to about 20 percent for Ag in Fe and to 40 percent for Fe in Ag, Cu in Fe, and Fe in Cu. This is the Figure 14b case, the crossing of the T_0 curves, with a mixture of the two crystalline phases in the central region. In the Fe-Ti case the terminal bcc phases extend only to 20 percent Ti in Fe and 20 percent Fe in Ti. The central concentrations are amorphous. This is the "T_0 gap" case (Figure 14a).

On the other hand, Nakamura's result on the Fe-Ag-Cu ternary alloys is not consistent with the predictions of the T_0 model. Crystalline deposits are formed at all concentrations on a water-cooled substrate and in amorphous form in the central region of the triangular concentration diagram on a liquid-nitrogen-cooled substrate.

EVAPORATED INDIUM-ALUMINUM FILMS

The results of (Yoji) Nakamura et al. on Fe alloys are consistent with those of Hazama, (Yoshio) Nakamura, and Nittono (Ref 22) on indium and aluminum. In and Al separate in the liquid phase and are mutually insoluble in the solid. Hazama et al. have evaporated and codeposited Al and In in vacuum and examined the deposited films by electron diffraction and electron microscopy. When deposited on a 288 K substrate there is no indication of solid solubility; what is seen is the diffraction patterns of Al and of In. When deposited on a 203 K substrate, up to 13 wt. % In is dissolved in the Al matrix.

BACK TO BASICS: MARTENSITIC TRANSFORMATIONS

We have described noncooperative, diffusionless transformations, the massive transformations. Another kind of diffusionless transformation is one in which there is no change in concentration but there is a change in structure. This can be from one symmetry to another, or from disorder bcc to ordered bcc (for example). The important point is that these are long-range-ordered, cooperative transformations, macroscopic, and hence with large energies. Of these, martensitic transformations are a particular subclass. The martensitic transformation is accomplished by a coherent shear of a finite, macroscopic volume of the crystal. There is a definite orientation relation between the parent and product crystals and a definite habit plane. In iron-base alloys, for example (in which martensite transformations are of great importance in hardening), the high temperature γ phase is fcc austenite, the product α' phase is bcc martensite. Figure 16 schematizes the crossing with temperature of the Gibbs free energies of the two phases. The transformation occurs quickly and at any temperature below onset, M_s ("start"). The fractional volume transformed increases as the temperature increment below M_s is increased (i.e., as the temperature is decreased). (There is also a defined temperature M_f at which the transformation is effectively complete, from a practical viewpoint.) The transformation can be reversed, and there are A_s

and A_f temperatures marking the termini of the reverse process (from martensite back to austenite). There is hysteresis in the transformation cycle. The martensitic diffusionless transformation, because of its speed of accomplishment, competes successfully with the slower but lower energy (equilibrium) partitioned transformation into austenite and ferrite of different concentrations (of Fe and Ni in the example cited).

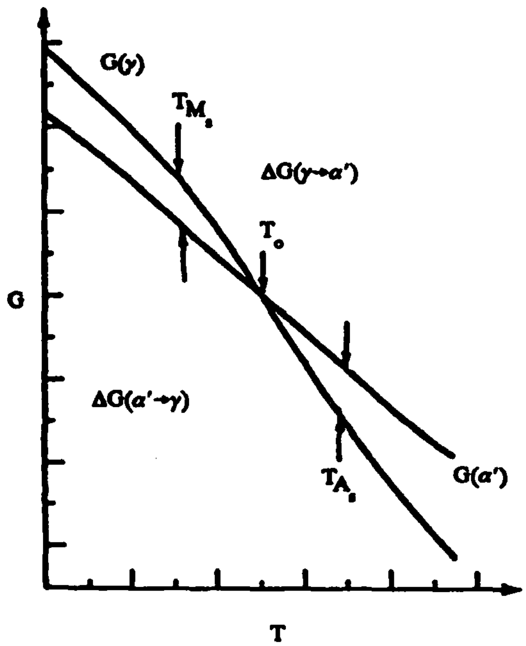


Figure 16. Free energy curves versus temperature of austenite (γ) and martensite (α′). The curves cross at T_o. At temperatures below T_o the free energy of martensite lies lower. The transformation from austenite to martensite begins at T_{Ms}, the temperature at which the free energy difference, ΔG(γ→α′), is sufficient to make the transformation favorable. The reverse transformation from martensite to austenite commences at the superheated temperature T_{As}, at which the free energy of martensite lies sufficiently above that of austenite to compensate for the interface and elastic energies accompanying the transformation (after Ref 3).

Nucleation of martensite strains the martensite particle and the matrix. This elastic energy plus interface energy, ΔG(γ→α′), effectively raises the martensite energy and must be compensated by supercooling by amount T_o-T_{Ms} down to T_{Ms} before any transformation takes place. In the reverse process martensite must be superheated to T_{As} to compensate for the elastic plus nucleation energy of austenite in the martensite matrix.

THE GIBBS FREE ENERGY OF STRESSED MATERIALS

The martensitic transformation is accomplished by a strain. It is a rather complicated strain, composed of a major shear component. If an external stress is applied to austenite in such a sense as to reinforce or to oppose strain in a crystal, the temperatures M_s, T_o, and A_s are shifted up or down accordingly. In the martensitic transformation, applied stress plays the same role as an external magnetic field in the ferromagnetic phase transition. It biases the two wells in the Gibbs free energy.

The experimentalist finds it convenient to control the intensive variables T, P, stress (Σ) rather than S, V, strain (times volume, to make it extensive), (εV). In Box 1 we developed a Gibbs free energy expression G(T,P,n). Consider it to be either constructed or Legendre transformed so that its fundamental variables are T, P, Σ, and n, or in the binary alloy case with mole fraction x of component B, $G(T,P,\Sigma,x_B n)$. And let us return to normal and negligible external isotropic pressure so that there are now three independent variables.

The Gibbs phase rule now has one more degree of freedom. There are now not one but three Clausius-Clapeyron equations along all phase boundaries: $\partial T_b/\partial x_B$, $\partial \Sigma_b/\partial x_B$,

$\partial T_b/\partial\Sigma$. Furthermore, curves for diffusionless transformations indicating equal free energies of the phases, $T_o(x_B)$, become surfaces, $T(\Sigma,x_B)$.

Sakamoto and Shimizu and coworkers (Ref 23) have studied stress-induced martensitic transformations in Cu-Al-Ni single-crystal alloys with the <001> direction parallel to the tensile axis. At fixed alloy concentrations and temperatures they use stress-strain curves to determine stresses for transformations from the same parent phase to different martensitic phases. Such data permit T_o versus stress curves to be constructed. By extrapolation T_o at zero stress for specific alloy compositions can be obtained for the various transformations. In this way they account for the series of transformations, from one martensitic phase to another, at fixed temperature, with varying Al concentration.

DIFFUSION

All the transformations we have dealt with so far, civilian or military, have been diffusionless. We must consider diffusion. Box 3 gives some of the concepts.

MECHANICAL ALLOYING

A great deal of effort has gone into the search for underlying principles of nonequilibrium phase formation, amorphization, solubility extension, and if one thing is clear, it is that there is no one principle that explains everything. This clearly has to be so, since competing kinetics are involved in what phase wins out, and kinetics can depend upon particular circumstances. Fujita (Ref 25) discusses a number of general conditions that result in amorphization during high energy electron irradiation and which he proposes should be applicable to other processes such as rapid quenching and vapor deposition.

There is a process so distinctly different from the rapid solidification and vapor quenching and other high energy processes we have discussed so far that different results might be anticipated. The process, mechanical alloying, is interesting in its own right. Mechanical alloying is about 20 years old (Ref 26). Alloys and even intimately codispersed metal/nonmetal composites that can be made either not at all or only with great difficulty by other means can be made by mechanical alloying. Metal powder particles are milled in a ball mill in an inert gas atmosphere. The particles are mixed and "kneaded" and flattened between the balls to ultrafine multilayers of the two metals. Continued milling refines the particles to very small size, but there is a lower limit, perhaps 10 to 20 nm depending upon the elements, beyond which no further size reduction occurs (Ref 27). As grain size is reduced the stress required for dislocation motion increases. And so plastic deformation, the process that has refined grain size down to a certain limit, is replaced by a different deformation mechanism, supposedly some superplastic process.

If unlike atoms attract less than do like atoms, there is no motive for further dispersal upon reaching the lower size limit. A fine particle mixture of pure elements, or a solid state colloidal suspension, will be the final product of ball milling.

But if $2V_{AB}<V_{AA}+V_{BB}$, and other factors such as size and electrochemical difference are favorable, the energetics favor interdiffusion, and this will occur if the temperature is high enough. Around each particle will grow a shell of increased penetration into the matrix. A common evolution with continued ball milling is first, the

reduction of particle size, then layering and mixing, mutual dissolution, and finally, but not always, formation of an amorphous phase. Thus the same energetics that favor intermetallic compound formation in the bulk phase diagram evidently favor solid solutions and amorphous phase formation in the ball-milled powders.

Box 3. Diffusion in Alloys

Define the concentration c as the number of atoms of some species per unit volume ($c=xn/V_o$ in previously defined notation), and j, the current density, as the net number of atoms of that species crossing unit area in unit time. To avoid vectors we consider only one-dimensional flow (along z). The current density is related to the concentration gradient by the diffusion equation:

$$j = -D \frac{\partial c}{\partial z} \tag{B3-1}$$

This is Fick's first law. D is the chemical diffusion coefficient, or chemical diffusivity. It depends upon the temperature. Since diffusion requires thermally activated hopping over a barrier,

$$D = D_o \exp(-Q/RT) \tag{B3-2}$$

Conservation of particles is expressed by the (one-dimensional) continuity equation:

$$\frac{\partial c}{\partial t} = -\frac{\partial j}{\partial z} \tag{B3-3}$$

Substituting Equation B3-1,

$$\frac{\partial c}{\partial t} = \frac{\partial}{\partial z} D \frac{\partial c}{\partial z} \tag{B3-4}$$

This is Fick's second law. The diffusivity of a species can depend upon the composition--how many sites are vacant or are occupied by a different species--and therefore upon position. When D is independent of position it can be brought out of the differential. This is the form in which we shall use the equation:

$$\frac{\partial c}{\partial t} = D \frac{\partial^2 c}{\partial z^2} \tag{B3-5}$$

When two species or more are diffusing the diffusivities not only can depend upon position but become coupled together, along with the concentrations, into an effective "interdiffusion coefficient" D_{int}. This has been treated by Darken (Ref 24).

MECHANICALLY ALLOYED Ag-Fe AND Al-Fe

P.H. Shingu and coworkers (Ref 28) have, by room temperature ball milling, made amorphous and nanometer grained structures of Ag-Fe and Al-Fe. Ag and Fe have no solid solubility. Even in the liquid state they are mutually immiscible. Under prolonged ball milling (600 hours) the Fe particles break down to a size of several tens of nanometers, but there is no amorphization. But at the interface between Fe and Ag particles there is some diffusion and solid solution formation. Solid solutions have also been formed by sputtering (Ref 29).

In contrast, Fe-Al forms intermetallic compounds. When ball milled, aluminum and iron particles break down to nanometer size. Diffusion of Fe into the Al occurs concurrently with refinement. Monitoring by Mossbauer spectroscopy of Al-24.4 at. % Fe reveals that the hyperfine field-split sextet of the Fe begins to decrease in intensity early in the ball milling, is gradually replaced by the quadrupole doublet of Fe in amorphous Al, and that incorporation and amorphization are complete at 454 hours of ball milling.

Shingu (Ref 28) suggests a model based on the metastable extensions of the equilibrium phase boundaries rather than the T_0 curves (see Figure 17). The intermetallic compound in the center of the diagram, being strongly bound, forms at a high temperature. If it did not exist, if kinetics suppressed its formation, the dashed two-phase boundaries would have extended down to some lower eutectic temperature, T_1, at which G_A, G_B, and G_{liq} would have had a common tangent. Suppose that because of a nucleation ΔG the intermetallic compound does not deposit from the liquid until an undercooled temperature T_2 is reached. If T_2 is low enough to be below the glass temperature T_g, then liquid within concentration range a to b would freeze to an amorphous homogeneous solid. Amorphous freezing is then more likely if the intermetallic compound lies in the neighborhood of a deep metastable eutectic. But of course we are talking about ball milling of solids and solid state reactions, not freezing from the melt. Perhaps the justification for invoking liquid phases and metastable extensions of their boundaries is the experimental evidence. As the powders are ball milled, the sharp x-ray diffraction lines of the two crystal phases give way to the broad diffuse maxima of amorphous materials.

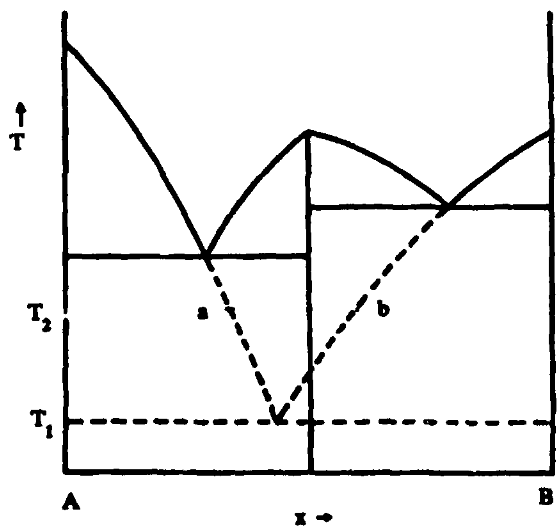


Figure 17. Phase diagram of a system in which the extensions of the equilibrium boundaries form a deep metastable eutectic. The temperature of this eutectic is illustrated as T_1. Interfacial nucleation energy suppresses formation of the solid above the undercooled temperature T_2. If T_2 is close to or below the glass temperature, then liquid in the concentration range a-b will freeze to an amorphous solid. The Cu-Zr system has such a deep metastable eutectic (after P.H. Shingu, Ref 28).

Shingu's deep metastable eutectic mechanism is not at variance with the "plunging T_0" criterion of Perepezko and Boettinger (Ref 10). In fact, it is more restrictive since the extended metastable phase boundaries must lie within the T_0 curves; if the extended phase boundaries do not cross the T_0 curves cannot. But Shingu stresses the importance of attractive interactions between unlike atoms. This is what distinguishes the Fe-Ag and Fe-Al cases.

MISCIBILITY GAP

Consider the equilibrium binary phase diagram in the case in which the two elements A and B fail to attract each other as much as do like atoms, so that $2V_{AB}-V_{AA}-V_{BB}>0$. (V_{ij} are negative.) The straight line between G_A and G_B in Figure 1 is then replaced by one that bows upward. Figures 18 and 19 depict the consequences. The mixing term, with infinite slope at the two extremes, always dominates near x=0 and x=1 (see Box 1). At high temperatures it dominates at all x, so that total G(x) has positive curvature at all x and only one minimum. There is then complete miscibility of the two components, and a homogeneous solid solution is the high temperature equilibrium state. As the temperature is reduced the free energy of mixing becomes less important. At some temperature there is a concentration at which $\partial^2G/\partial x^2=0$. Below this temperature a two-phase region develops in the phase diagram. At lower temperatures the G(x) curve has a local maximum and thus two minima. A heterogeneous mixture of two phases, their concentrations and amounts found by the tangent construction and lever rule, has a lower free energy than the homogeneous alloy. Figure 19 shows α_1 and α_2 regions at the extremes separated from the $\alpha_1+\alpha_2$ two-phase region by the incoherent phase boundary.

SPINODAL DECOMPOSITION

Figure 18 also shows a trace of the points of inflection, the two concentrations for each temperature, at which $\partial^2G/\partial x^2=0$. This trajectory is the spinodal of Figure 19. For concentrations within the spinodal, $\partial^2G/\partial x^2<0$; for concentrations in the two border regions between the two branches of the spinodal and the incoherent phase boundary, $\partial^2G/\partial x^2>0$. We have said that α_1 and α_2 have the same structure, the same symmetry. They differ in concentration. To achieve the equilibrium state atoms must segregate. They do so driven by the energetics of being with their own kind. Within the spinodal the chemical diffusion coefficient, which is proportional to $\partial^2G/\partial x^2$ (at that temperature and local concentration), is negative. Spontaneous separation of an initially homogeneous alloy by diffusion into heterogeneous phases is known as spinodal decomposition (Ref 30).

The reader will have recognized the spontaneous symmetry breaking of a continuous symmetry, such as in a ferromagnet at the second order phase transition, the Curie temperature. Once again, tilting the diagram because of the difference between G(A) and G(B) corresponds to the application of an external field on the ferromagnet.

Figure 20, from Hansen and Anderko (Ref 31), is the Au-Ni phase diagram. Below about 800 °C there is a miscibility gap. The two phases, α_1 and α_2, are both face-centered cubic, but with different lattice parameters. α_1 is the terminal solid of the Au lattice with Ni in solution; α_2 is the terminal solid of the Ni lattice with Au in solution.

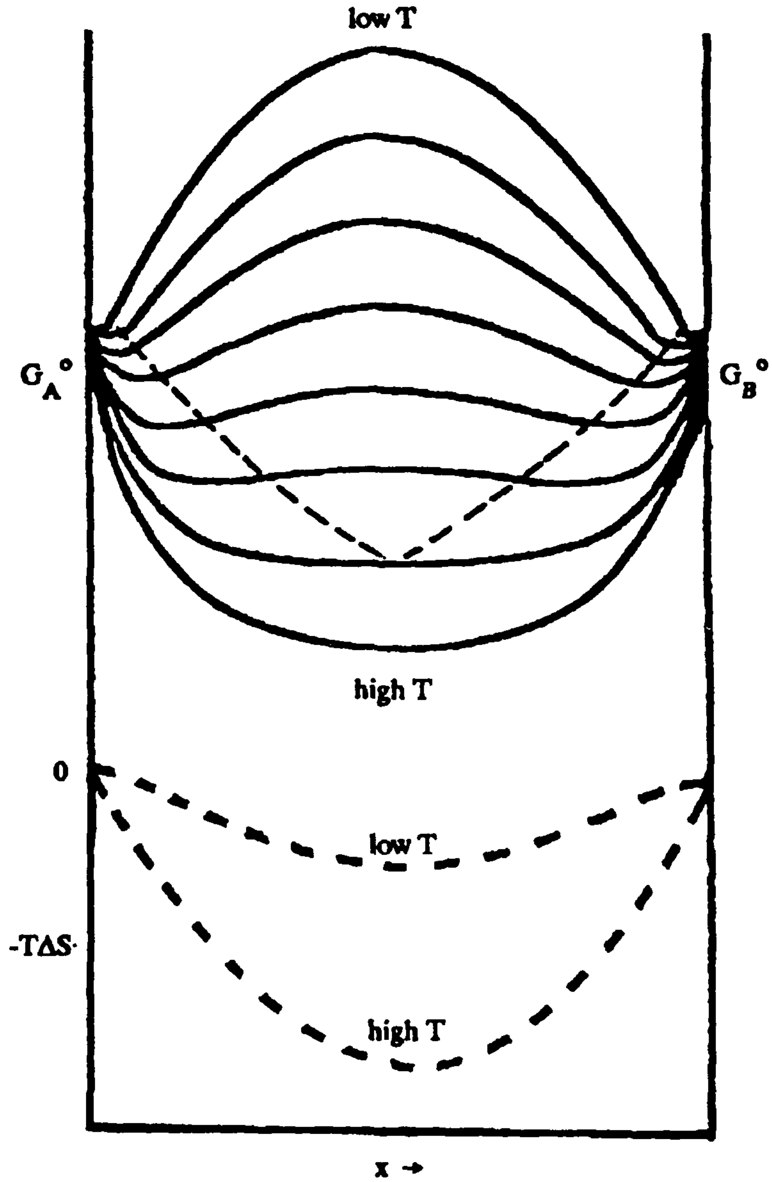


Figure 18. Free energy curves at a number of temperatures in a range in which a miscibility gap develops. Because the attraction between like atoms is greater than between unlike atoms, a curve of the internal energy as a function of composition would have negative curvature rather than the linear relation shown in Figure 1. The mixing entropy contribution to the free energy, the lower dashed curve of Figure 18, is small at low T but large at high T. The sums of the internal energy and the entropy terms are shown as a series of free energy curves. At high temperature the entropy term dominates and the free energy has positive curvature at all concentrations. At some temperature there is a concentration at which the curvature is zero. Below this temperature a maximum develops in the free energy curves. Near $x=0$ and $x=1$ the slope is always negative and the curvature is positive because of the powerful logarithmic term in the entropy part of the free energy. The figure shows as a dashed line the locus of points at which the second derivative is zero.

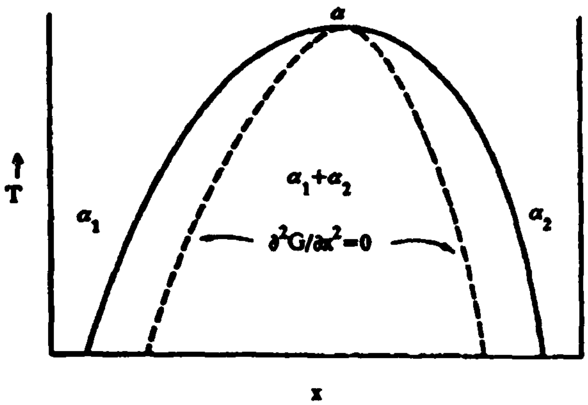


Figure 19. Phase diagram resulting from free energy evolution of Figure 18. The solid line is the "incoherent" phase boundary. α_1 and α_2 have that same symmetry, that of α, but usually have different lattice constants, since one is the terminal lattice of A and the other of B. Within the concave solid curve the equilibrium state is a heterogeneous mixture of α_1 and α_2 of different compositions. The dashed curve within the incoherent boundary is the spinodal. This was shown in Figure 18. In the central region, within the spinodal, $\partial^2G/\partial x^2$ is negative. A homogeneous material formed by rapid cooling from above the incoherent boundary will spontaneously decompose by diffusion, if the temperature is not too low. Homogeneous compositions in the two sectors between the spinodal and the incoherent boundary, regions in which the second derivative is positive, can only decompose by large fluctuations in local free energy. They are relatively long lived, even at temperatures where diffusion occurs.

A miscibility gap leads to metastability. Suppose that by one means or another--perhaps rapid cooling--one has been able to form a homogeneous single-phase alloy of concentration within the miscibility gap, the (incoherent) phase boundary of Figure 19. The lowest free energy would result from separation into two phases. Will it occur? At any temperature there are spontaneous local fluctuations in temperature and in concentration. At what concentrations can small fluctuations relax the homogeneous alloy into a two-phase material? It can do so when a small fluctuation reduces the energy, when $\partial^2G/\partial x^2<0$. Within the spinodal a homogeneous rapidly quenched alloy (but at a temperature where diffusion is still possible) will relax to the partitioned mixture. Precipitation hardening occurs by the formation of metastable precipitates (Guinier-Preston zones)--extremely fine particles formed by decomposition of a homogeneous alloy with a miscibility gap. This was first studied in Al-Zn, Al-Ag, Al-Cu but occurs also in many oth ˙ alloys.

In the two strips of the phase diagram between the spinodals and the phase boundaries (Figure 19) the quenched homogeneous alloy is stable against small fluctuations. It can only relax (through discontinuous precipitation) by getting over or around large free energy barriers to the equilibrium partition of the phase boundary, and so it initiates and grows at grain boundaries and dislocations, from surfaces or discontinuities.

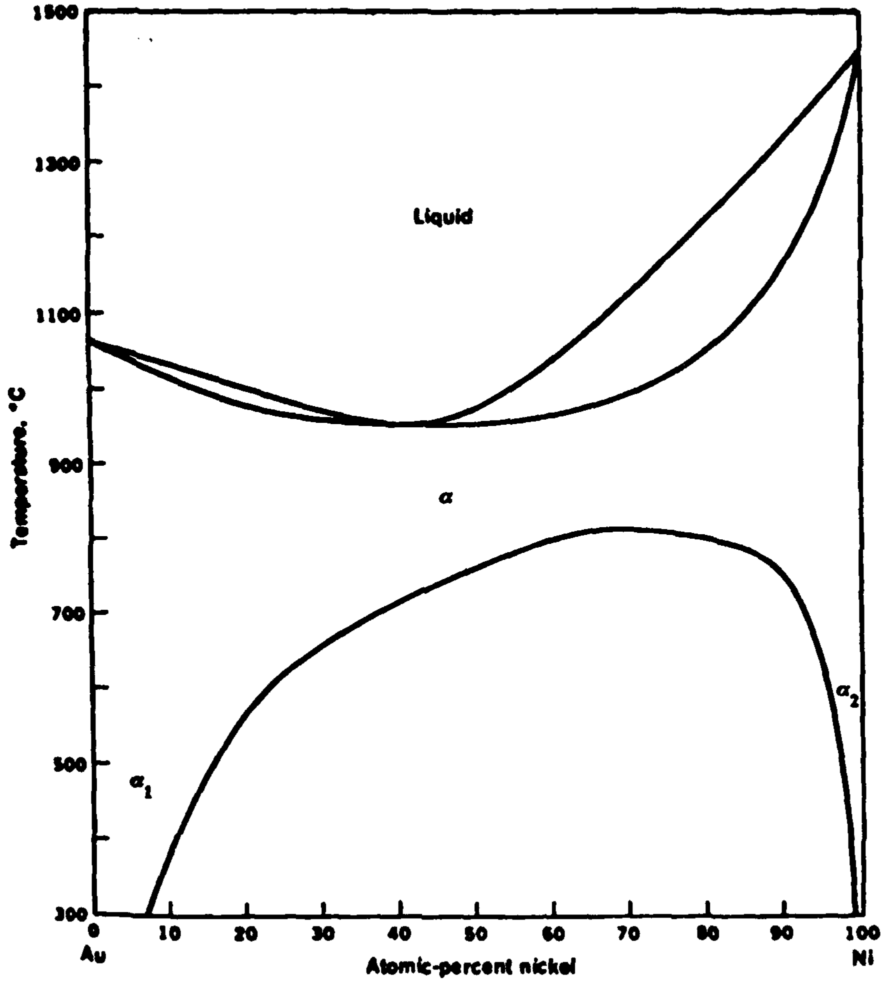


Figure 20. Au-Ni phase diagram. M. Hansen and K. Anderko, *Constitution of Binary Alloys*, 2nd ed. (McGraw-Hill Book Company, New York, 1958). Reproduced with permission.

INCOHERENT AND COHERENT SPINODAL DECOMPOSITION
(Ref 30)

It frequently happens that fine precipitates in spinodal decomposition, which as we have said have the same symmetry as the host, line up in orientation and phase exactly with the host matrix. They are then said to be coherent. The crystal lattice continues on uninterruptedly through the precipitate particles. But since the precipitate is of different concentration, it can and often does have a distinctly different lattice constant. The precipitate particles and surrounding matrix are strained. As usual this elastic energy shifts the crossings of the free energy curves, the tangent points, and the phase boundary. There is also an interfacial energy term with its ΔG. Generally speaking, incoherent particles have a higher interfacial energy and a lower elastic energy than do coherent precipitates. Typically the precipitate is periodically arrayed, with well-defined wavelength, and characteristic particle shapes. The larger the change in lattice constant with concentration, $\partial a_0/\partial x$, the larger the strain energy (which goes as the square of that change). This can depress the miscibility gap for coherent precipitation hundreds of degrees below the incoherent boundary pictured in Figure 19.

IRRADIATION-INDUCED SPINODAL DECOMPOSITION

The true spinodal curve, the real boundary within which spontaneous decomposition will occur, is the second derivative (with concentration) of the entire G, including all contributions. Thus the spinodal as well as the equilibrium phase boundary depend upon strain and interfacial energy. If the strain is relieved the spinodal will be raised to a higher temperature. Irradiation of some alloys raises the spinodal temperature several hundred degrees. This is of considerable importance for materials used in nuclear engineering. **Nakai, Kinoshima, Kitajima, and coworkers** (Ref 32) have studied the effect of high (1 MeV) electron irradiation on Ni-Au, Au-Ni, Fe-Mo, Cu-Ni, and Cu-Ti alloys. Au-Ni and Ni-Au are particularly revealing because of the large difference in size of the two ions and consequent large coherent strain. We have remarked that within the spinodal the alloy decomposes periodically with a definite wavelength λ (and wavenumber $k=2\pi/\lambda$). The Cahn-Hilliard theory (Ref 30) relates the wavenumber (square) of the coherent strain to the difference between the actual temperature of the sample and the coherent spinodal temperature at that average concentration. Nakai et al. irradiate at various temperatures and show that the Cahn-Hilliard expression is well satisfied, the wavenumber of the modulation changes properly with irradiation temperature. Extrapolating to zero wavenumber (infinite wavelength), they find a coherent spinodal temperature under irradiation. They then show that continued irradiation at room temperature raises this coherent spinodal temperature hundreds of degrees--actually by 600 K in the case of Au-Ni, in which the elastic strains are very large when there is no irradiation. Irradiation has relieved the strains and thus raised the coherent spinodal temperature. The authors show that what irradiation does is to assist in the formation of strain-relieving imperfections. The authors suggest that rows of tiny interstitial loops are formed in expansive strain regions and vacancies in compressed regions.

THERMAL INSTABILITY OF THE GaAs/AlAs SUPERLATTICE

As an example of a morphologically metastable system Turnbull (Ref 1) cites compositionally modulated films. An instructive example of the applicability of diffusion to metastable structures is the work of Osamura et al. (Ref 33) on superlattices. Because they can be atomically engineered, because of their extremely high speed and low power consumption, semiconductor superlattices are important electronic device materials (Ref 34). The highest mobilities are attained in the narrow bandgap group III/V semiconductors such as GaAs. On a GaAs substrate, many--perhaps 3,000 for optoelectronic applications--alternate, planar, very thin layers of, say, $Al_{0.4}Ga_{0.6}As$ and GaAs are deposited epitaxially, by molecular beam or chemical vapor epitaxy. The Al ternary compound has a wider energy gap between its valence and conduction bands than has GaAs; the former acts as an electronic barrier and the latter as the well. For some pairs of III/Vs, especially GaAs with $Al_xGa_{1-x}As$ and InP with $Ga_xIn_{1-x}P_yAs_{1-y}$, energy gap and refractive index can be modified, with lattice matching better than 0.05 percent.

These superlattices are metastable; the group III elements Al, Ga, and In and the group V elements P and As are mutually soluble in the GaAs structure, as the substitution formulas in the previous paragraph indicate. Osamura et al. have annealed AlAs/GaAs superlattices at a series of temperatures and studied the diffusion and collapse of the structure.

The theory as presented in Box 3 is not complete. In multi-species diffusion, it is the interdiffusion coefficient that is effective. There are also contributions to the effective diffusion coefficient from the sharply modulated strain and from the steep concentration gradients. Osamura et al. show these latter contributions are negligible compared to unity and that the effective diffusivity at wavenumber k is approximately equal to the interdiffusion coefficient D_{int}. For our purpose it is sufficient to examine the consequences in terms of the mathematics in Box 3.

At time 0 the concentration distribution of some species, say Ga, is:

$$c(z,0) = c_o(1 - \sin kz) \qquad (12)$$

Here k is the wavenumber of the superlattice periodicity. A solution of Equation B3-5 is

$$c(z,t) = c_o[1 - \exp(-D_{int}k^2t) \sin kz] \qquad (13)$$

As time passes the oscillatory concentration diffuses to uniformity. The relaxation time is $1/D_{int}k^2$. This makes sense: the larger k, the shorter the wavelength and the shorter the distance atoms must diffuse to fill in the low density regions. The relaxation time goes as the square of the wavenumber because the continuity equation has the second derivative of concentration with respect to position: it is the curvature that provides the driving force. Equation B3-2 shows the diffusivity (it is also true for the interdiffusivity, which is a linear combination of diffusivities of the several species) to rise exponentially with temperature. Osamura et al. have measured the temperature dependence of D_{int} in an AlAs/GaAs superlattice with a wavelength of 1.98 nm, in all 600 nm thick. Each layer is only a few atoms thick. The amplitude of the sinusoidal oscillation is monitored by x-ray diffraction. Figure 21 shows their data. In one experiment they held the sample at various increasing temperatures, 10 seconds at each temperature. In another they held the sample for 1.2 ks at each temperature. It appears that there are two diffusion mechanisms with different activation energies, one effective below 1,080 K and one above. The activation energy for the lower temperature diffusion is 41.6 kJ/mol. Osamura et al. estimate from this that the lifetime of such a superlattice at room temperature would be 1 year. Since the lifetime goes as the square of the wavelength, superlattices with longer periods would last correspondingly longer. Although most superlattices now employed have much thicker layers, the push is toward shorter wavelengths for higher speed.

PRESSURE EFFECTS: AMORPHOUS-CRYSTALLINE TRANSITION IN SE-TE

Crystalline $Se_{80}Te_{20}$ (c-$Se_{80}Te_{20}$) has a trigonal structure and is a semiconductor. At a pressure in excess of 125 kbars, c-$Se_{80}Te_{20}$ transforms to a phase with metallic conductivity.

Se-Te of various proportions can also be prepared in amorphous form (a-Se-Te) by quenching from the melt. **Mushiage, Tamura, and Endo** (Ref 35) have studied the effect of pressure on a-$Se_{80}Te_{20}$, a semiconductor with a resistivity several orders of magnitude higher than that of the crystalline form. a-$Se_{80}Te_{20}$ undergoes a sharp semiconductor-metal transition at a pressure of 100 kbar. At this pressure the structure transforms from amorphous to a layered arrangement (c′-Se-Te) something like that of the planar zigzag chain arrangement of high pressure Te and quite different from the trigonal structure of the Se crystalline phase. X-ray diffraction and resistivity measurements show the metal-semiconductor and structural transitions to coincide.

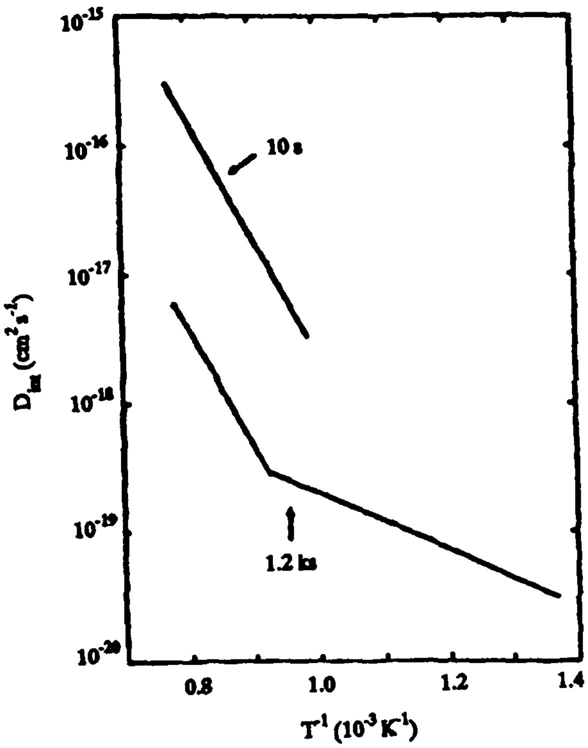


Figure 21. Temperature dependence of the interdiffusion coefficient in an AlAs/GaAs superlattice. The wavelength is 1.98 nm (after Ref 33).

The metastable structural transition is entirely reversible. Upon repeated application and release of pressure the material transforms back and forth between the semiconducting amorphous and metallic layered forms. Moreover, a metastable phase cycle can be performed in the temperature, pressure plane. The cycle begins (point a on Figure 22) at room temperature and atmospheric pressure with a-$Se_{67}Te_{33}$ (in the experiment described by Mushiage et al.), formed by quenching from the melt. Application of a pressure of 100 kbar or so causes transformation to c′-Se-Te (point b), and this form is retained when the temperature is reduced (point c). If the final temperature is sufficiently low, -50 °C, the material remains in c′ structure under pressure quench to atmospheric pressure (point d). The amorphous state is then recovered upon heating to room temperature.

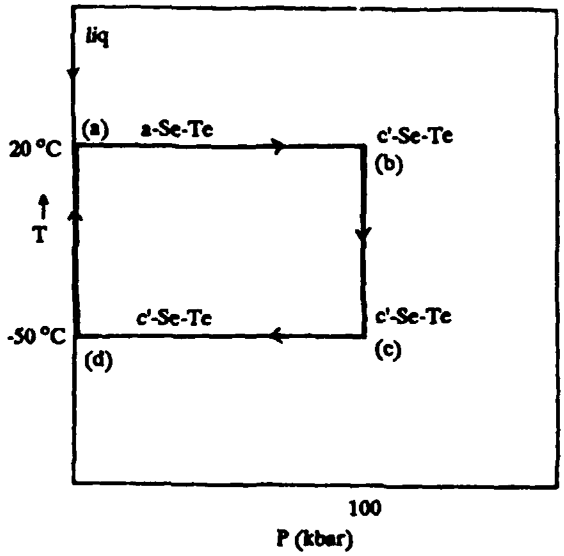


Figure 22. Metastable structure cycle in Se-Te. Amorphous Se-Te (a-$Se_{67}Te_{33}$) is quenched from the melt to point a on the figure. Under pressure this is compressed to a layered metallic form, c′-Se-Te, point b, which is then cooled to -50 °C at high pressure, point c. When the pressure is released to point d the metastable crystalline form is retained. Upon heating to room temperature the material reverts to the amorphous structure.

THE "MELTING" OF ICE BY PRESSURE

As the last example we wish to discuss some remarkable high pressure research by Mishima et al. (Ref 36). Figure 23 shows the phase diagram for water. The melting temperature of ice I decreases with increasing pressure. The diagram shows an extrapolated metastable extension of the water-ice I phase boundary. At low temperatures, below the glass temperature, ice I subjected to high pressure can be brought to a region of the diagram where in equilibrium it should be ice VI. Will it transform to ice VI, will it become some intermediate crystalline phase, will it remain ice I because of the extreme viscosity, or will it "melt" to the "liquid" on crossing the metastable phase boundary? It does the latter. Starting with ice at a temperature of 77 K, when the pressure is increased to about 10 kbar the solid sample becomes amorphous. (Ice IX, on the other hand, when subjected to 25 kbar at the same temperature, does not transform.) The transition begins at about 10 kbar and is complete at 15. Releasing the pressure, a significant fraction of the volume remains amorphous at zero applied pressure. On warming, the sample transforms to ice I. Upon repeated recycling the ice I-amorphous transition follows the same trajectory in the stress-strain plane. The authors emphasize that similar behavior is to be expected in any material in which the melting temperature decreases with pressure. At a temperature below the glass transition, something interesting--perhaps amorphization--should happen upon increasing the pressure beyond the metastable extension of the phase boundary. Mishima et al. list numerous candidate materials, including graphite, diamond, silicon, germanium, and indium antimonide.

CONCLUSIONS

There are a large number of techniques available to produce metastable phases of metals and alloys. These techniques include rapid solidification, mechanical alloying, ion implantation, ion and electron irradiation, and a variety of vapor phase processes such as chemical vapor deposition and sputtering. The answer to the question "How does one achieve metastability?" is on the one hand straightforward for all of these processes. The reactants must be at a higher free energy than the possible metastable phases. Moreover, the relevant kinetic processes necessary for the transformation from reactants to metastable or stable phases must be such that a metastable phase forms. But for detailed and specific application of these broad, general concepts, a more sophisticated understanding is required and often is not available. For some metastable phases, especially amorphous phases and metastable extensions of solid solubility, extensions of equilibrium phase boundaries and T_0 curves are important tools. This is so in the case of two elements having a large negative heat of mixing and extremely different atomic sizes. The T_0 approach is evidently valid for rapid solidification, mechanical alloying, ion and electron irradiation, and vapor deposition processes. In other cases, however, such as forming metastable solid solutions under conditions in which the stable phases are immiscible, vapor phase deposition can be used to form metastable phases that cannot be formed by other processes.

While the techniques employed and the systems studied are similar in Japan to those in the United States, the Japanese effort in metastability is impressive and significant.

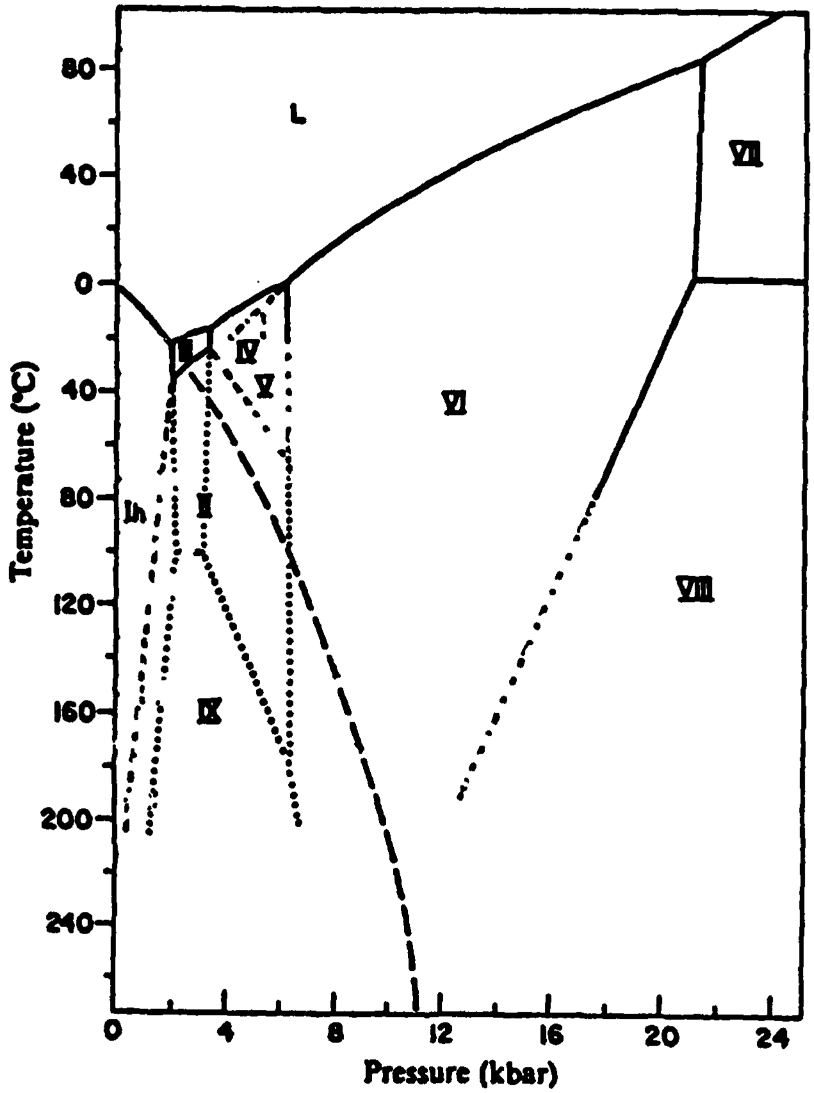


Figure 23. Phase diagram for ice in the pressure-temperature plane. The melting line of ice I is extrapolated as a dashed line. When pressure is applied to ice I at a temperature so low as to inhibit atomic rearrangement to an equilibrium state, amorphous ice is formed (after Ref 36).

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STRATEGIC TECHNOLOGY MANAGEMENT IN JAPAN: COMMERCIAL-MILITARY COMPARISONS*

Michael W. Chinworth

Government reliance on the private sector is equally evident in defense and commercial sectors in Japan. Government-business collaborative relationships in commercial research projects have carried over into the defense field, as have technology management practices among private companies. Indeed, defense technology strategies among private firms are in many respects extensions of commercial strategies. Therefore, in examining technology management strategies and practices applicable for defense in Japan, it is necessary to gain an understanding first of practices in these areas.

SUMMARY

The salient points of Japan's overall research and development (R&D) efforts that have particular importance to the defense sector include:

- Emphasis on private sector activity--The private sector serves as the main player in R&D expenditures. Its time horizon is fixed on the long term. Management strategies emphasize examining the utility of technological applications within the context of overall corporate goals.

- Limited government role--The government role as an initiator is most prominent when risks are highest and the potential payoffs are not evident in the foreseeable future. As soon as a budding technology appears to offer more substantial gains at lower risk, the R&D effort is turned over to the private sector. Government strategies assess technological inputs in terms of their net effect on the national economy.

- Strong institutional and informal integration of government and business R&D activities--Government and business interact at several formal and informal levels and in doing so develop a clear consensus on R&D directions. While the private and public sectors do not necessarily see eye to eye on all major issues, there nevertheless is a degree of cooperation and

*This is a modified version of a paper completed under contract to the U.S. Office of Technology Assessment (OTA). As such, it does not necessarily reflect the analytical findings of OTA. In addition to the sources noted at the conclusion of this report, many of the observations contained in it were drawn from interviews with U.S. and Japanese executives and government officials during the period of 7-20 November 1988 in Tokyo. The author wishes to thank the Office of Technology Assessment for its support, as well as the many individuals that took time from their schedules to discuss these concepts. The author assumes sole responsibility for factual errors as well as any viewpoints reflected in this paper.

coordination that is not always evident in other countries. Furthermore, government ministries themselves encourage integration of perspectives and a comprehensive outlook on technological efforts through such mechanisms as seconding government employees in various agencies and ministries.

- Emphasis on dual use, multiple application technologies--Advanced technologies with a single or limited application are not as attractive as those offering multiple applications. The R&D management process tends to weed out technologies with limited applications or defer their development. While spinoffs are sought, an equally if not more important consideration is "spin-on": the utilization of technologies to produce new products or even industries. The close integration of business and government activities along with an emphasis on focusing R&D efforts on the private sector help assure the development and utilization of dual use technologies. It is not a case of developing, for example, a process or product in a government military laboratory and then attempting to find applications in commercial fields. To a large extent, military and commercial interests are merged by the institutional structures and management attitudes evident in business and government.

- An emphasis on research collaboration--In both military and civilian fields, technological research and development programs with particularly far reaching implications tend to be organized around private sector consortia in a manner that encourages cross fertilization at preliminary stages while assuring benefits from free competition in later development stages. Collaboration is not the sole means of bringing technology into commercial or military marketplaces, but it does play a unique, important role.

INTRODUCTION

Although defense research and development expenditures still account for only a small part of Japan's annual budgets, the government is placing significant emphasis on the development of indigenous weapons systems and the utilization of domestic technologies for defense applications. The defense policymaking establishment recognizes that Japan's capability to defend itself against potential threats, particularly in the face of a weakening U.S. presence in Asia and a decline of American economic power, rests on its ability to field superior technology in the form of advanced weapons systems. The 1988 issue of *Defense of Japan* (Ref 1), the annual statement of defense policies issued with cabinet approval, declares that

> ...it is particularly important to continue efforts to maintain and improve the technological standards related to military equipment required for national defense in years to come. Japan is the second largest economic power in the Free World and has a high level of industrial technology capable of independently carrying out research and development projects in the field of high technology. The Defense Agency is conducting research and development by taking advantage of technological expertise accumulated in the private sector...It has been increasingly necessary for

the country to direct more positive efforts to research and development on equipment.

Japanese defense technology strategies are intertwined with a broader process of technology management in government and industry that emphasizes the nurturing of dual use technologies to assure Japan's security in the broadest sense during the coming century. It is essential to look beyond narrow definitions of security to appreciate the thrust and implications of Japanese defense technology management. Security does not extend solely to protection from a perceived military foe. Rather, it includes a multitude of economic and political factors that tend to unify interests in business and government in Japan. One must therefore examine the roles and perceptions of these groups to grasp the Japanese formulation and implementation of technology management policies as part of a larger economic strategy. As evidenced by the priority on developing dual use technologies with multiple applications, Japan's technology policies are generated and implemented in a manner that merges economic, security, and industrial policy considerations. As a result, the line between purely defense and civilian technologies is consciously blurred to assure maximum utilization of emerging applications and processes.

This paper examines the mechanisms and policies that result in this policy mix by reviewing (1) the most important player in Japanese research--the private sector, (2) the nature of industry-government interaction in research and development, (3) the players and processes in defense decisionmaking, and (4) the research patterns evident in commercial research that are manifested in defense related efforts as well as the specialized role of defense research offices.

R&D IN THE PRIVATE SECTOR

Japanese management of defense related technology must be addressed in the context of overall research and development in Japan, and particularly in terms of the role of industry and government-industry collaboration in achieving targeted goals. Only recently have economic, political, and institutional constraints on defense spending moderated sufficiently to identify a more specific defense component in those efforts. Research and development funding is dominated by the private sector in Japan. Because of that dominance, business practices in commercial development figure prominently in defense related R&D.

The United States still spends more in aggregate on research and development than Japan. Nevertheless, Japan now spends a higher portion of its gross national product (GNP) than the United States on research--2.8 percent for Japan compared to 2.7 percent for the United States in 1985. The Japanese government estimates that this will increase to 3.4 percent of Japan's GNP by 1990 and 5.3 percent by 2000, compared with 2.9 percent and 3.4 percent for the United States over the same period (Ref 2)*.

*The budget for the Technical Research and Development Institute (TRDI)--the research and development arm of the Japan Defense Agency--accounts for just under 5 percent of total government R&D expenditures. Research in private firms accounts for the remainder of total defense-related R&D.

Approximately 50 percent of all U.S. R&D spending is related directly to the military (estimates go as high as 70 percent). The percentage for Japan is far smaller (although increasing), with 80 to 90 percent of all funds--government and private sector combined--directed toward commercial applications. Private sector R&D dominates the Japanese technology process. Whereas half of all U.S. research is funded by the government, approximately 75 to 80 percent of Japan's total R&D allocations reside in the private sector (Ref 2).

All of these factors have been cited as reasons for Japan's efficiency in applying new or improved technologies in products. But it is not a matter of funding alone. Business and government give priority to projects that will provide a net technological gain to domestic economy and/or serve as a source of innovation for other industries and sectors. If there is a consensus that the potential payoffs are likely to be very significant, investors and researchers will allow even greater time spans to allow fruition of the technology. Innovation is viewed not simply as a means of achieving economic breakthroughs but also as an ongoing process that must be incorporated into every phase of development and production. Japanese firms will invest in a series of incremental improvements in products despite the costs while U.S. firms often look for more sweeping and perhaps elusive breakthroughs.

One basic difference between the U.S. and Japanese systems of innovation is involvement of engineers, researchers, and other technical specialists in both determining priorities among potential research projects as well as their participation in the design and development phases of new products. Production and manufacturing considerations are merged with development and design stages virtually from the initial consideration of a promising technology all the way through the production phase. These considerations are incorporated into product design and thus necessitate fewer costly and time consuming modifications at later stages. It is still difficult to determine if the same can be said without qualification in defense production, but it would not be surprising if similar attitudes and practices prevailed.

Another fundamental point is that in many cases Japanese firms are not necessarily leaders in underlying technologies but do excel in process technology--the mundane but essential capability to produce goods more efficiently than other competitors. Again, this is attributable in part to close cooperation and collaboration among designers and production personnel at the earliest phase of a product's development.

A final characteristic is the commitment of top management to promoting technological advances within their companies. The participation of higher level managers and corporate officials varies from one firm to the next, but there is corporate wide awareness of and support for ongoing research. Funding decisions frequently are made at senior levels. Research results are circulated systematically throughout corporations, even within sales and marketing divisions. (Shogo Sakakura of the Japan Society of Science Policy and Research Management details these and other characteristics of Japanese research management in "A Fact Finding Survey of Research Management in Private Research Institutes" (Ref 3).

R&D IN THE PUBLIC SECTOR

In terms of government funding, the Science and Technology Agency (STA), Ministry of International Trade and Industry (MITI), and Ministry of Education constitute the three largest players in Japan's government directed research and development. (For the purposes of this paper, I will focus on the first two. Much of the size of the Education Ministry's budget is attributable to the fact that it is responsible for managing educational research facilities.) Total government funding will reach ¥1.71 trillion ($13.7 billion at current exchange rates) during the current fiscal year, with STA and MITI accounting for ¥431 billion and ¥221 billion, respectively (see Table 1).

A broad consensus on the value of research and development efforts exists in Japan that provides a stable political and economic environment for the pursuit of long term goals. Bureaucratic organization and more politically oriented activities help assure the preservation of that consensus. STA, for example, is organized under the office of the prime minister while MITI's research programs report directly to the head of the ministry. At the broadest level, scientific research trends are monitored and influenced by advisory councils associated with the office of the prime minister. These councils fulfill multiple roles, including facilitating the creation of a cabinet wide consensus on appropriate government policies and allocation of resources. They also legitimize initiatives developed in the private or public sector through public endorsements. Council reports can provide stimulus in specific fields. Space exploration, for example, has become a national priority in part because of the role played by these advisory councils in articulating government visions and stirring the national imagination.

Table 1. Science and Technology Budget Allocations, FY 1988 (millions of yen)

Ministry/Agency	Total Allocations	% Change From Previous Year
Education	812,954	4.2
Science and Technology Agency	430,955	1.3
International Trade and Industry	221,226	-0.1
Japan Defense Agency	82,700	11.6
Agriculture, Forestry, Fisheries	66,642	-0.2
Health and Welfare	44,059	10.8
Posts and Telecommunications	30,279	4.3
Transportation	14,627	0.8
Environmental Protection Agency	7,752	-2.0
Foreign Affairs	6,417	1.9
Others	14,894	0.6
Total	1,706,504	3.1

Source: Ministry of International Trade and Industry, Agency of Industrial Science and Technology

Government laboratories and research institutes fulfill a variety of roles in the Japanese R&D process. They do not simply create new technologies or initiate larger research projects. While often serving this purpose, government facilities are equally important for their role as neutral testing grounds to verify results achieved in private sector labs and to carry research to a point where it becomes more economical to pursue it in private sector facilities. Given these roles, which are clearly perceived in both industry and government, it is understandable that considerable business-government interaction takes place at the level of individual researchers, their supervisors, and the directors of respective facilities.

Despite the efficacy of Japanese R&D efforts, the process is not faultless. Interministry integration and cooperation is not always as thorough as it could be. There have been instances in which ministries have competed against one another for prominent roles in research initiatives, forcing political compromises that also wastefully duplicated efforts. (Competition over budgets for space activities comes to mind). Important initiatives can fail as well, even when there is a clear consensus of views in government and industry. An aerospace effort in the 1950s, for example, produced the YS-11, a small passenger aircraft intended for commercial use that fell far short of its ambitions.

By the same token, there is not necessarily a nationwide or government wide consensus on the value of defense production and research for the overall economy. While it has been argued here that the country has embarked on a policy emphasizing domestic research and development of advanced weapons systems, that policy is not universally embraced nor is it without frictions. The Ministry of Finance (MOF) retains, as an article of faith, the philosophy that virtually any spending on defense comes at the expense of the economy (thus necessitating active lobbying by industry to convince the ministry of the domestic economic value of, say, an indigenous fighter-support aircraft). A number of major research efforts within civilian ministries and agencies have clear potential for military applications. Among them are artificial intelligence research, high performance plastics, fine ceramics, advanced alloys, jet engine research, and deep-sea mining systems, to mention only a few. Although both the public and private sectors are examining possible military applications, the projects nevertheless are justified primarily because of their expected positive impact on the civilian economy.

RESEARCH COLLABORATION

Selective collaborative research, particularly in the precompetitive phase, plays an important role in realizing technological gains in the public and private sectors. Collaborative undertakings are widespread but they are not necessarily the rule in Japanese research efforts. The nature, timing, and participants of collaborative efforts vary from one field to the next. Nevertheless, they are prominent features in Japanese efforts to bring technology to the marketplace. Informal and formal processes identify promising research fields or significant trends. Once a government and industry consensus has been reached on more specific avenues of research, what frequently follows is the establishment of a government-industry collaborative effort or a government sanctioned research consortium involving the participation of multiple private sector interests. As research proceeds, greater competition is introduced to hasten the introduction of a product to the marketplace. For an analysis of collaborative research in Japan, see Richard J. Samuels' "Research Collaboration in Japan" (Ref 4).

Interviews with corporate figures suggest that many companies are less committed to the consortium approach than they might have been in earlier decades, arguing that important resources are being diverted from corporations to government sanctioned consortia without demonstrating sufficient potential for tangible gains. Some firms have suggested that their own resources and decisionmaking processes are sufficient for stimulating technological advances and, while not resenting the government role, believe that it should be reduced or shifted to other forms of involvement in R&D. These same companies, however, remain participants in deference to government relations considerations and out of the competitive concern that a development or breakthrough will indeed arise from a consortium to which they would not be a party if they did not participate.

This situation is not likely to change in the near future. In the area of defense technology, for example, there are a large number of industry consortia, including those in composite materials, advanced turboprop research, and fighter aircraft. Japanese managers feel that the market is too competitive to risk a totally independent course of action. Cost is another factor favoring cooperation as well, especially in large scale projects originating in, but not necessarily limited to, the defense field. Finally, projects such as the FSX are seen literally as once in a lifetime opportunities that if neglected could lead to the complete loss of important capabilities.

DEFENSE DECISIONMAKING

It is in this environment that Japan establishes policies governing the management of its defense technology base. Defense issues have assumed greater prominence in recent years. Nevertheless, Japanese defense policymaking remains constrained and is subject to negotiation among often competing interests. Historical and institutional factors help explain this. For example, broad defense policies--and thus decisions regarding allocation of national resources to major defense R&D programs--are not the sole domain of the Japan Defense Agency (JDA). JDA is not as autonomous or influential within the Japanese government bureaucracy as the Department of Defense (DOD) is in the United States. Budget constraints have remained severe throughout the postwar era. Until recently, popular and political support within Japan for defense has been muted or limited, curtailing the agency's relative influence in the government. The agency has been unable until recent times to attract Japan's most promising college graduates, who preferred joining more prestigious government ministries including MOF and MITI.

Institutional factors also influence JDA's role as one among many in determining defense policies. Multiple players with differing agendas and perspectives interact to generate policies that can be accepted by the government as a whole. The most direct form of influence over defense policies is the MOF's budgetary power. In the more centralized budget process of the Japanese government, MOF has wielded considerable influence aimed primarily at restricting the growth of defense budgets under the assumption that such spending constituted a drag on the economy. In recent years, however, defense proponents have been successful in securing spending increases far higher than those for other agencies.

Despite this newly found influence, however, major defense policy decisions are only recommended by JDA, subject to the approval of the Security Council of Japan, a formal body chaired by the prime minister that includes the ministers of finance, international trade and industry, and foreign affairs, along with such officials as the director general of the Economic Planning Agency (EPA). The Security Council replaced the weaker National Defense Council in July 1986 and is the final arbiter of such policies as the agency's five-year procurement plans. The Security Council's influence means that much of Japan's defense policymaking process is intertwined with nondefense interests. Diverse and wide ranging interests influence the defense policymaking process through organs such as the Security Council. These interests include domestic industrial concerns (as represented by MITI), fiscal and monetary interests (represented by MOF), and macroeconomic policy outlooks (in the form of EPA interests). MITI's aircraft and ordnance division is particularly influential in Japanese procurement decisions.

Influence by other ministries is exhibited within JDA itself. Many of the key positions in the agency are occupied by officials seconded from other ministries. The director general of the procurement bureau usually is headed by a representative from MITI with experience in the ministry's aircraft and ordnance division. The finance bureau is staffed by a Ministry of Finance employee.

Incorporating other ministry and agency interests in the defense policymaking process need not be a divisive dynamic. Indeed, while different agencies' interests often compete with one another in this situation, this process nevertheless contributes to the formation of policies with widespread government support. Interagency negotiation of defense policies tends to integrate economic, security, and industrial policy perspectives in addressing defense policies. While the presence of seconded officials within its halls might have drawbacks from JDA's perspective, it also means that a growing cadre of government officials have been integrated in the defense policymaking process--including the domestic economic, industrial, and developmental aspects of defense policies--by virtue of their service within JDA.

TECHNICAL RESEARCH AND DEVELOPMENT INSTITUTE

It is within this context that the Technical Research and Development Institute (TRDI) operates. Organized as a division within JDA, TRDI is the agency's primary research organization and is headed by a civilian who overseas three administrative departments along with four uniformed directors who supervise research and development in ground, naval, and air systems, as well as precision guided munitions. Conceptualization, design, and prototype responsibilities are fulfilled at this level. Research centers carry out survey research, testing, and evaluations to enable further development on specific systems. Authorized manpower is 1,179, which includes 256 uniformed personnel rotated from the three branches of the Self-Defense Forces (SDF). TRDI maintains five research facilities in Japan that test and evaluate a broad range of weapons systems and technologies (see the Appendix for a complete list of the facilities and their areas of research). The institute has no prototype manufacturing capabilities, relying on privates sector capacities instead (Ref 1).

The R&D component of the Japanese defense budget has grown at over 10 percent annually for the last five fiscal years. TRDI's total budget in FY 1988 (1 April 1988 - 31 March 1989) comes to ¥81.8 billion ($682 million at current exchange rates), approximately 2.21 percent of Japan's total defense budget. On 19 January 1989, the cabinet approved a 6.1 percent increase for FY 1989 to bring that total to ¥86.7 billion (Ref 1,5).*

As a matter of policy, JDA is seeking to continue its upward R&D spending trend and boost total R&D expenditures to 2.5 percent of the defense budget by the end of FY 1991 (see Table 2). Much of this reflects decisions to proceed with "big ticket" items for utilization by the three services. Major projects include the SSM-1 surface-to-surface missile (from which antiship and other derivatives are anticipated); a new main battle tank to succeed older, domestically developed models; the XSH-60J antisubmarine helicopter, a codevelopment project with the United States designed to replace outdated aircraft; and, last but certainly not least, the FSX next generation fighter-support aircraft, another codevelopment effort led by Mitsubishi Heavy Industries from Japan and General Dynamics from the United States. JDA and TRDI also have proposed four specific technology areas for codevelopment projects with the United States. In October 1988, the two countries initialed an agreement to codevelop new missile guidance technology (Ref 1,6).**

TRDI's early postwar effort was directed largely toward reinventing the military technology wheel. With limited resources, bureaucratic constraints, a lack of popular support, and other factors hindering R&D efforts, the organization was not capable of launching high risk projects of its own accord. That situation has begun to change. With greater public acceptance of defense policies, TRDI has been able to recruit promising technical graduates from leading educational institutions.

* JDA had sought an increase of 12.9 percent for TRDI's FY 1989 budget, more than twice what was approved. The FY 1989 budget had just gained cabinet approval as this article went to press. By the time of its publication, the budget most likely will have been approved by the Diet, Japan's parliament, with only minor changes, if any.

** The phrase "codeveloped" often is used in Japan in reference to modification programs involving for example, changes to a U.S. airframe or other structure to accommodate introduction of Japanese electronics. The missile homing project, however, does appear to involve more fundamental efforts.

Table 2. Technical Research and Development Institute Spending, FY 1968-88 (percent of total defense spending) (after Ref 1)

Fiscal Year	Percent
1968	2.01
1976	1.21
1984	1.49
1985	1.84
1986	1.95
1987	2.08
1988	2.21
1989[a]	2.21
1991[b]	2.50

[a]Preliminary.
[b]Goal.

TRDI was established to develop independent weapons development capabilities and enhance the growth of the domestic arms industry. Limited direct participation in defense related R&D has been a guiding principal from the outset, in part to minimize government budget outlays but also because of the assumption--still active today at least within the Ministry of Finance--that defense spending constituted a burden on the civilian sector and therefore should be limited (private industry and other government ministries do not necessarily share this view, but MOF controls the purse strings). For a discussion of the origins and early projects of TRDI, see Reference 7. Thus, to a large degree TRDI has managed its defense technology to date according to its impact on the domestic economic/technological base. The institute does not necessarily target the development of technologies to field specific weapons systems.* A consistent criterion for the selection and nurturing of technologies has been the impact of any given technology on the commercial sector. The chances that a given technology will be targeted for development are higher if it contributes to the overall industrial base and will provide opportunities for other spinoffs/spin-ons. For example, emphasis placed on radar development reflects industry and government interests as wide ranging as phased array systems for fighter aircraft, 360° radar for commercial air traffic control, and collision avoidance systems for automobiles. Composite materials is another field offering similarly diverse applications.

*Indeed, JDA has been accused of foregoing the acquisition of systems readily available from foreign suppliers until TRDI could develop the domestic technology necessary to develop a comparable system--thus enhancing domestic industry capabilities and spinoff/spin-on opportunities as well. Despite the high priority given by the Ground Self-Defense Forces to fielding advanced tanks, for example, deployment was delayed until a purely domestic model was developed to TRDI's satisfaction. Journalistic accounts of the Japanese procurement system also accused the government of delaying consideration of short range surface-to-air missile systems for air base defenses until the Tan-SAM was fully developed. More recently, industry backers of a domestic fighter-support aircraft to replace aging F-1s called in 1987 for further feasibility studies and/or the development of a domestic prototype aircraft with the tacit support of the Air Self-Defense Forces when it appeared that then JDA director general Kurihara would decide in favor of a codevelopment project with the United States or the acquisition of an American aircraft.

Thus, an important element of the Japanese strategy is much like one used in drafting professional football players. Rather than find the best player for a specific position, TRDI often "drafts" the best technology available at the time regardless of the position it plays. What is important is that it is an "impact player" capable of producing benefits to the "team" over the long run. The U.S. security guarantee, of course, has contributed to a situation in which Japan has more flexibility in making these decisions. In viewing the utility of this approach for the United States it is important to keep these comparisons in context. Allowing for contextual differences, however, does not make the underlying principal any less valid for foreign observers.

The combination of a government posture that historically has been concerned about drains on the civilian economy and the emphasis on broad applications of new technologies has led to close government-business interaction in defense areas, reflecting practices in commercial sectors. TRDI works with industry in both formal and informal manners. In many cases, the organization simply monitors research already underway in private companies. In others, it carries out preliminary research that ultimately is handed over to the private sector once it has reached a stage where risks have been reduced and the potential for the technology has proven itself. The development of the F-1 fighter support aircraft, SSM-1 cruise missile, and T-2 trainer all illustrate that pattern. In some cases, companies will pursue their own R&D projects with implicit understanding that ultimately it will be funded by JDA. In most cases, firms avoid labeling such research as defense R&D due to political considerations.

Heavy reliance on the private sector was reinforced by a reorganization in July 1987 that eliminated minor research programs that could be pursued more effectively by private sector research facilities. In addition, TRDI's role was defined to include research that lacks an immediately identifiable demand in commercial sectors. This could be an important development for TRDI's institutional role, perhaps representing a judgment by JDA that fielding advanced weapons systems will require selective development of specialized technologies with primarily military applications.

At the same time, however, a flexible approach was emphasized to maximize the utilization of commercial technology in military systems--all with the ultimate aim of making Japan equal or superior to other countries in terms of its defense technology base (Ref 8). This outlook is summarized in the current white paper (Ref 1):

> The Defense Agency will positively utilize the private sector's technology on the basis of its excellent technology in the field of microelectronics and new materials including ceramics and composite materials. Particularly in the area of basic research the Defense Agency will rely heavily on the technology pooled in the private sector. Furthermore, the Defense Agency, carrying out a technological research project to integrate private technology into future high-technology equipment, will build it up as a system that will meet the unique operational requirements of this country. Accordingly, the Defense Agency will achieve effective improvement of superior equipment capable of competing with technological standards of foreign countries.

Institutional and informal mechanisms comparable to those outlined earlier tend to reinforce utilization of commercial capabilities for defense in both research and manufacturing. Close links plus the overriding philosophy emphasizing commercial benefits/inputs help assure first that military related research benefits the commercial sector (spinoffs) and second that commercial, off-the-shelf technologies are utilized to the fullest extent possible in military systems (spin-ons). Furthermore, even in the case of "purely military" technologies, TRDI can be expected to follow the pattern of relying on private sector development as soon as feasible. Business and government will also seek to optimize applications in defense and commercial sectors.

PRIVATE SECTOR INTERACTION

The private sector plays an important role in developing a consensus on overall R&D trends as well as specific projects through individual company contacts and various industry associations. The most influential of these groups most likely is the Defense Production Committee (DPC) of Keidanren--the Federation of Economic Organizations. (For a dated, but still largely accurate, portrayal of the Defense Production Committee in action see Reference 9.) The DPC consists of about 10 percent of Keidanren's total membership of 800 industrial companies and over 100 financial institutions.

The DPC officially serves four functions:

- Compile basic data on defense production.
- Collect and circulate information relating to defense production developments and trends.
- Promote cooperation among defense contractors.
- Coordinate defense and nondefense industries and interests.

A fifth, but unofficial, purpose is to promote the interests of its members among government agencies and policymakers. Given these objectives, it is not surprising that the DPC plays a significant role at least as a forum for discussion and dissent among contractors on defense issues. The committee will refuse to take stands where industry wide concurrence is impossible or momentarily beyond reach, but it will promote positions on which there is a clear-cut consensus of views. The group issues an annual report on defense related issues. It consistently has favored higher domestic production rates and indigenous weapons development. Most recently, the group has called upon the government to allocate greater budgetary resources to defense related R&D, supporting JDA's target level of 2.5 percent of the total defense budget. (For other Keidanren DPC perspectives, see Reference 10. The Japan Ordnance Association expresses its policy positions on pages 480-482.)

Since its establishment in 1952, virtually every chairman of the DPC has come from Mitsubishi Heavy Industries (MHI). While it is beyond the scope of this paper to examine the implications of that dominance, it is nevertheless worth noting that such consistency has given MHI a means of assuring its preeminent status as Japan's number one defense contractor and of projecting its views of defense issues on the domestic industry as a whole.

Other groups playing comparable roles include the Japan Ordnance Association, the Society of Japanese Aerospace Companies (SJAC), and the Japan Shipbuilding Industry Association. In addition, the Japan Technology Association was created in 1980 with the support of such diverse commercial firms as Sony and Honda Motors. These associations, along with other industry interests such as trading companies, can have a significant role in the formative stages of major policy developments. This is due in part to the lack of outside, independent consultants available to U.S. government agencies to address pending policy and procurement issues.

Senior executives of leading defense contractors who are also officials of these associations routinely serve on key advisory panels--*shingikai*--for MITI, the defense agency, and other government agencies. These panels, like the Defense Science Board in the United States, are an important conduit of information and influence between business and government. Moreover, it is not uncommon for major companies to provide JDA with technical analyses of competing weapons systems for use in determining a final selection for procurement. It is not unusual for governments in other countries to turn to private interests for such analyses, but Japan lacks the Booz-Allens or Rand Corporations that normally would provide them in the United States. Since these same firms also act ultimately as the developers, manufacturers, or procuring agents for these systems, their involvement in such fundamental activities gives them significant opportunities to shape the course of future policies in a manner that serves private sector interests. In research and development projects, it also allows them insights into government perspectives that might otherwise be limited or unavailable altogether.

Influence and interaction of industry is further strengthened by the increasingly common practice among major defense contractors, industry associations, and trading companies of hiring retired, senior JDA and SDF personnel as advisors in defense matters. This does not differ markedly from the United States except to the extent that such relationships are the result of longer term interaction than might be evident in the U.S. experience. Furthermore, potential access to higher levels of government across the board is great if the new advisor retired from a senior position after serving in several ministries throughout his career.

Companies frequently attempt to anticipate and prepare for major policy developments through the formation of informal study groups on specific issues or trends. For example, the aerospace department of a major trading company might form such a group to collect data and examine satellite utilization and technology to identify potential business opportunities. Participants would include representatives of comparable departments or divisions from other companies, and by informal agreement the group would work under the supervision of a lower mid-level executive of the organizing company. Government officials might informally participate as well. Ultimately, the head of the trading company's aerospace department would become involved if significant opportunities were identified by lower ranking staff members. At that point, the focus would shift to one or more of the industry associations and the study group would disband.

Such early interfirm cooperation has the effect of consolidating industry perceptions toward emerging business opportunities and can also help identify specific roles for individual companies once projects move into the research, development, and production phases. Firms are motivated to continue participating in these arrangements because of their desire to secure some portion of the business resulting from a major procurement decision. The Japanese defense market is an oligopoly and government procurement decisions reinforce a pattern in which only a few firms can develop specific manufacturing and production capabilities. Given that situation, no one firm will secure the lion's share of a major procurement order. Their participation in the formal and informal mechanisms outlined above, however, can help assure that they receive at least a part of the business.

A point to emphasize again here is that firms at this stage are not necessarily approaching these areas in terms of their potential for military business per se. Instead, a broad focus is maintained in which business opportunities are identified and analyzed in terms of their overall relationship to a company's strategic plans and objectives. In the United States it is often noted that the Defense Department does not field technology, but weapons. In the Japanese case, where private sector and commercial ministry interests play a very important role, it is safe to say that JDA fields neither technology nor weapons, but products.

This is due in part to the fact that unlike the situation in the United States, there are few clear-cut defense contractors in Japan. Mitsubishi Heavy Industries, for example, secures on average about 25 percent of JDA's total annual procurement budgets, translating to only 15 percent of its total sales. Distribution of JDA contracts diversifies dramatically once MHI's share is accounted for. Of major contractors, only one--Japan Aviation Company--depends virtually entirely on defense contracts for its survival.

Firms are diversifying, however, to emphasize defense related sales. MHI's 15 percent of sales in the defense field, for example, has grown from just over 7 percent a decade ago. Nissan Motors now officially describes itself as a defense contractor in its corporate charter. Fujitsu, Ltd. has established a corporate goal of increasing defense sales 20 percent annually (Ref 11). As mentioned early, firms as diverse as Sony and Honda are keenly interested in defense sales and applications for existing and new technologies. But rather than looking at defense as a new field requiring different marketing strategies, companies are *incorporating their defense strategies as new* components of broader commercial plans, again with an emphasis on achieving maximum gains from any given technology or product.

SELF-IMAGE, EXTERNAL EVALUATIONS, AND IMPLICATIONS

Japanese policymakers and observers alike increasingly view the country's technological capabilities as second only to those of the United States--and even then just barely in terms of many specific technologies. The 1987 STA white paper concluded that within the past two decades, Japan's inherent technological strength and its potential for future technological development relative to the United States surpassed West Germany, France, and the United Kingdom (Ref 12). A recent assessment of Japan's future role in the world--*Nihon no Sentaku* (Japan's Choices)--completed by a MITI sanctioned commission, has determined that Japan leads the United States in many critical fields and is closing ground on virtually every other technology that will prove of importance in the coming century. This includes space communications, launch vehicles, robotics, large scale integrated circuits, civil aerospace, biotechnology, and artificial intelligence, to name only a few (Ref 13). The Defense Science Board of the United States concurred that Japanese capabilities in dual use technologies offered great potential for use in advanced U.S. systems in its 1984 report on industry-to-industry arms cooperation. A subsequent DOD task force identified a more specific range of technologies (Ref 14).

These assessments represent an increasing appreciation of Japan's capabilities abroad, but they are even more significant in terms of the country's domestic outlook because they show a heretofore restrained confidence in its capabilities to lead the world in technologies that have both commercial and military importance. This development of itself, of course, should not necessarily cause concern to the United States and other allies of Japan. There are signs of payoffs in the form of U.S.-Japan cooperation. The two countries concluded notes in November 1983 to allow military technology exchanges and in 1987 Japan agreed to participate in the Strategic Defense Initiative (SDI) (the first SDI contract involving a Japanese firm was signed recently). Furthermore, the two countries have embarked on a less heralded project--the development of a new missile homing system--that could be an even more promising indication of things to come.

Nevertheless, it is important to view the Japanese R&D effort in perspective. Japan equates technological advancement with its chances for survival in the future. The 1987 STA white paper concluded that virtually 50 percent of all Japanese economic growth in the 15 years since the oil shocks was attributable to advances in the domestic technological base, compared with 20 percent at most for the United States (Ref 15). (It is safe to say that in terms of defense outlays, much of the growth on the Japanese side would be attributed to the dual-use, multiple application strategy in which a focus on solely military technologies has been discouraged. For the United States, no doubt an opposite conclusion would be reached; namely, that excessive attention to strictly military R&D has served as a drag on the overall economy.) These gains have resulted in productivity improvements and the creation of new demand for products that simply did not exist a decade ago. Small wonder the government places heavy emphasis on maintaining this pace to assure the continued vitality and growth of the Japanese economy in the future. The United States has concluded that its chances for continued global influence rest in large part on the health of its technological base. A critical element in this strategy, however, is the underlying assumption that allied cooperation and technology exchanges are essential to assure mutual survival. One must ask if Japan--with its emphasis on retaining technology to assure its own survival--shares that assumption. The answer to that question could have profound implications for the conduct of this country's policies with Japan in the coming decades.

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Appendix

TRDI RESEARCH FACILITIES

First Research Center

First division:	Explosives; ammunition; small arms; artillery
Second division:	Armor; antiballistic structures
Third division:	Camouflage; parachutes
Fourth division:	Hydrodynamics; battleship technology (structures; noise reduction)

Second Research Center

First division:	Communications; computer applications; information systems integration
Second division:	Radar; electronic warfare; microwave antennas/components
Third division:	Electro-optical systems; infrared systems

Third Research Center

First division:	FSX aerodynamics, stability/control, structure and system integration; helicopters; missiles, RVPs
Second division:	Air breathing/rocket propulsion systems
Third division:	Missile guidance; fire control systems; sensors; navigation systems

Fourth Research Center

First division:	Mine warfare; protective structures
Second division:	Transmissions, suspension systems, engines, and other vehicle subsystems
Test division:	Vehicle testing (tanks)

Fifth Research Center

First division:	Sonar; underwater acoustics
Second division:	Torpedoes; mines
Field test/evaluation division:	Torpedo, mine testing
Kawasaki branch:	Shipboard degassing; magnetic sensors

Source: *Boeicho, Jieitai* (Boei Kenkyukai, 1988), 289-293.

AN AMERICAN PERSPECTIVE ON ISS '88, THE FIRST INTERNATIONAL SYMPOSIUM ON SUPERCONDUCTIVITY

Donald H. Liebenberg

The First International Symposium on Superconductivity (ISS '88) was held from 28-31 August 1988 in Nagoya, Japan. Highlights of the symposium include the general agreement that international cooperation in the precompetitive research stage is important. Review papers by R. Schrieffer, G. Deutscher, A. Malozemoff, and others brought an international flavor and valuable assessments of the field to this meeting. The new superconducting classes, Bi-Sr-Ca-Cu-O and Tl-Ba-Ca-Cu-O, were extensively discussed.

INTRODUCTION

This symposium was organized by Professor S. Tanaka, vice president, International Superconductivity Technology Center (ISTEC). A total of 950 participants, including 100 from overseas, attended--nearly twice the number originally expected. Professors Robert Schrieffer and Malcolm Beasley gave the special and plenary lectures the first morning. Four Japanese industrialists presented plenary lectures in the afternoon: Drs. T. Nakahara, Sumitomo Electric; T. Mitsui, Tokyo Electric Power; H. Tanaka, Railway Technical Institute; and Y. Takeda, Hitachi, Ltd. These talks and others will be summarized in this article.* Public interest in this topic of superconductivity is high in Japan: Professor Schrieffer's lecture was carried on television throughout the country.

Highlights of this symposium include general agreement that international cooperation in the precompetitive research stage is important; Professor Kent Bowen, MIT, noted that more than 300,000 foreign students are attending U.S. colleges and universities. The indication of Japanese plans, both those funded, such as the approximately $50 million investment in ISTEC, the support of the magnetically levitated train, the project to build a 150-ton electromagnetic propulsion ship, and the activities directed toward devices are where superconductivity is expected to impact. The Japanese intend to provide steady and long-term support. Industrial efforts in both conventional and the new high temperature superconductors are approached with an intent to develop a marketable product. Scientific highlights are the main topic of this article. The recent report by Professor P.T. Wu, Taiwan, on the appearance of zero resistance in a four-layer thallium compound at 160 K was a late addition to the program. There was no confirmation of his results, although several groups with excellent capabilities in the preparation of thallium superconducting materials have attempted similar work. Wu noted that no Meissner effect was observed above 120 K for any of the 22 samples that showed zero resistance above 130 K.

*Since there were multiple sessions at this symposium this article is necessarily incomplete, reflecting the preferences of the author.

THEORY

Professor Schrieffer gave an excellent summary of superconductivity developments from the discovery at Leiden in 1911 and especially of his personal recollections of the birth and evolution of the Bardeen-Cooper-Schrieffer (BCS) theory. Schrieffer discussed with eloquence and clarity his recent efforts to describe the new high temperature superconductors by invoking spin (and also charge) bags, yet comparison with experimental results remains to be made. His view of the inseparability of spin and charge variables is a point of difference with the RVB model of P. Anderson. As the Japanese theorist, Professor H. Fukuyama, remarked, so far theorists have not been too helpful in this turmoil, although we could be on the verge of another important role for theory in condensed matter physics. Fukuyama has tried holons but now believes a Bose condensation of holons will not work, so he may be moving toward an analysis with charge and spin not separated.*

Professor G. Deutscher examined the question of electromagnetic properties. Critical currents are higher in thin film crystals than in bulk single crystals. Other anomalies include the irreversibility line and temperature dependence, the fast magnetization relaxation, and the large microwave absorption at small applied fields. His phenomenological theory examines these anomalies from the viewpoint of the short coherence length in high temperature superconductors. The consequence of the internal Josephson junction weak coupling interface and the weak pinning is suggested to lead to the glassy properties or the giant flux creep as discussed by Dr. A. Malozemoff.** Deutscher is able to obtain the 3/2 power law dependence on T_c-T for H_{c2} that is not predicted by mean-field theory. With a short coherence length there is expected suppression of the order parameter near an interface or surface that is reduced at temperatures well below T_c. This model describes the critical current variations including the increased j_c with reduced powder size. He concluded that grain boundaries did not provide pinning sites; rather point defects, such as impurities, are suggested. This model was based on core pinning only.

Dr. A. Malozemoff, IBM Yorktown, gave an interesting discussion of the giant flux creep model. A thermal activation process over some barrier, potential, or distribution of potentials is found with an Anderson-Kim type model to describe the critical current, introducing a frequency dependence to the critical current. The irreversibility line was apparently measured in most early experiments to find H_{c2} and the ac susceptibility is dependent on frequency. The method gives a more accurate measure of H_c. He also emphasized the importance of understanding the pinning mechanism (an aspect of superconductivity not addressed by the early BCS theory). An interesting comment about the value of measuring critical currents with the field

*The question of the oxygen states as used in the Goddard theory compared to the states assumed by Schrieffer drew another contrast in theoretical approaches.

**As observed by C. Rossel, IBM Zurich, when the high temperature superconducting material is cooled down in zero field and then a field is applied, the magnetization depends on the time of measurement after the field is changed. This is noted by Deutscher as a typical glass effect.

parallel to the current was made and is indicative of the help that phenomenological models may provide to experimental studies.*

Professor S. Maekawa discussed his method for interpreting optical conductivity data to give a density of states. This work is one of the attempts to understand the remarkable phase diagram of the $(La_{1-x}Ba_x)_2CuO_4$ system and its extreme sensitivity to Sr or Ba doping. In a closing discussion on the future, Professor de Jongh suggested an analogy with liquid helium where both gap and gapless type or BCS and Bose condensation theories apply and gave some reasons for a Bose condensation to be responsible for these high temperature superconductors. He noted the increase in transition temperatures from 2 mK to 2 K in the helium systems as BCS or Bose theory applies. Thus the theoretical field would seem to remain quite open at this point. However, the constraint of theories by the complexity of the materials may not be avoided.

EXPERIMENTAL RESULTS

No earth-shaking (probably a poor phrase to use in Japan) results were announced at this symposium; however, very substantial works to understand and improve the new superconductors, Bi and Tl, and significant studies to control microstructure and understand flux pinning were reported by several groups. Also a wide range of superconductivity in various compositions in the Bi and Tl systems was reported.

Professor Beasley opened the experimental discussions with a plenary lecture on historical developments in materials and phenomena. The conjunctions of events--Bardeen-Cooper-Schrieffer microscopic theory, Ginzburg-Landau-Abrikosov solution of vortices in a type II superconductor, the isotope effect measurements, the Josephson pair tunneling, and the A-15 development--all in the late 1950s and early 1960s, led to a golden period and the beginning of practical engineering of superconducting magnets. The Josephson discovery and prompt experimental verification began an electronics development that continues. In the post early 1960s period a search for exotic superconductors, $BaPbBiO_3$, and organic heavy fermions involved the materials work that was, of course, to prove so essential to the high temperature superconductors. He noted that so far as he knew there is no evidence of a superconductor in which the electron pairing mechanism is other than through electron-phonon interaction.

Dr. J. Tsai, NEC, reported improved tunneling spectroscopy results using a thin yttrium film on a strontium titanate substrate edge against a lead block. A very reproducible signal was observed showing lead and YBCO gap information. By raising the temperature from 4.2 to 10 K the lead gap signal disappeared. By selected crystal orientation the gaps for films parallel and perpendicular to the Cu-O planes were determined: $2\Delta/kT = 5.9$ and 3.6, respectively. The measured gap was independent of the impedance of the contact. For Bi films on MgO substrates the results are not yet reliable.

*The emphasis on phenomenological theories as guides to experimental studies is made in the *Workshop on Research Opportunities in Superconductivity-1988*, Copper Mountain (supported by the Office of Naval Research and the National Science Foundation).

Dr. H. Maeda, National Research Institute for Metals, described his discovery of the Bi superconducting material and recent work on the stabilization of the high temperature phase with substitution of lead. About 20 percent lead remains after sintering a 50-percent substitution and a sharp diamagnetic signal at 107 K is observed. The high temperature phase $Bi_2Sr_2Ca_2Cu_3O_x$ (2223) was obtained by solid state reaction and sintering in the narrow temperature range 870 to 880 °C for 5 to 10 hours. The Kyoto University group of Professor Bando was noted to have obtained this phase starting with a small amount of lead ($Bi_{0.7}Pb_{0.3}$), Sr, Ca, $Cu_{1.8}O_x$. Some lead diffuses out during sintering and leaves about 20 percent. A sharp diamagnetic signal is obtained. The magnetic field dependence was determined (subject to above differences in interpretation) where H_{c2} was 60 T at 77 K and 140 T at O K (extrapolated). The value $(dH_{c2}/dT)_{T=Tc}$ = 1.8 T/K was found. The critical current of the bulk samples was over 200 A/cm² for a 300-hour sinter time; a pressed sample, which apparently produced orientation of the grains, gave 700 A/cm², although a steep decrease with magnetic fields was still observed.

A most interesting part of Dr. Maeda's report was the success in making a 1330 filament wire in a silver sheath starting with powder. Again a nearly complete higher temperature phase was obtained with an anneal of 830 °C and 50 hours, but the critical current was not reported since he was uncertain of the contributions of the silver sheath.

Professor A. Hermann described his work on the thallium system that he discovered. He noted that thallium was natural since it has the right size in the 3+ valence state. Between the discovery in October 1987 and publication in *Nature* January 20, 1988, the time was spent in patenting. A good Meissner effect was found, and a strong electron paramagnetic resonance (EPR) signal measured at San Diego showed an onset T_c of 120 K. The thermoelectric power was measured by Trefny at the Colorado School of Mines, and a critical current of 700 A/cm² shows interesting plateaus as the magnetic field is raised by small amounts. The trapped flux and suspension in a magnetic field (similar to the Wu observation for Bi) was demonstrated, but only four samples have shown this suspension effect. Professor Hermann has also made a Josephson junction with a lead needle and found a Fraunhofer-like pattern versus magnetic field, suggesting the presence of Cooper pairs. He has studied compositional variation to try and get additional Cu-O planes in the unit cell. A new processing technique was announced where the toxic thallium is added in a separate vapor phase processing. Temperatures of 935 °C for 10 minutes are required to give $T_c(0)$ = 100 K. This process has been used with thick wire and films. There is hope to further reduce the thallium fraction required by substitution of indium oxide (T_c ~ 95 K).

Several reports were given on the studies of Bi and Tl classes of materials (Drs. Raveau, Cava, and Subramanian). Professor Raveau, whose solid state chemistry developed the lanthanum material that Bednorz and Müller showed was a possible superconductor, discussed the four families of high temperature superconductors now known. He noted an interesting matrix--that will appear in the Proceedings--of these families, $(AO)_n(ACuO_{3-y})_m$. The thallium compounds have many types of defects, so there is opportunity to intercalate and synthesize new compounds. He has obtained seven Cu-O planes in some regions, as observed with an atomic resolution microscope.

Dr. R. Cava, AT&T, discussed the new superconductor Ba-K-Bi-O, a 3D superconductor with T ~ 30 K. He suggested the valence state Bi^{4+} is actually disproportionated into $Bi^{3.5+}$ + $Bi^{4.5+}$. In the normal state the material is a semiconductor but nearly metallic; the normal state susceptibility is diamagnetic. The higher Bi charge gives a shorter Bi-O bond length. The original crimped silver tube preparation technique actually depends on a slow leak that was initially inadvertent in the process. A simplified process has been announced by Argonne National Laboratory, and at both the University of Houston and AT&T single crystals have been produced.

Dr. Subramanian described the DuPont synthesis work on the Bi and Tl compounds. As an example, the following table lists some of the compositional variations that show superconductivity in the thallium system. Results from both the Subramanian and Raveau reports are included.

Tl	Ba	Ca	Cu	O_x	T_c (K)	Cu-O Layers
2	2	0	1		84-90	
2	2	1	2		98-110	double
2	2	2	3		115-125	triple
2	2	4	5		140?	
1	2	1	2		70-80	double perovskite
1	2	2	3		?	
2	2	3	4		104	newest Raveau
etc.						

The Subramanian report emphasized the need for some impurity of lead in the Tl-Sr-Ca-Cu-O system in order to stabilize the higher temperature phase. He disagreed with the conclusion of A. Hermann that pure Tl (2223) had a T_c ~ 20 K, noting some 500 samples made to explore these phases. (In a following comment Hitachi results seemed to agree with Hermann.)

The Bi system $Bi_2Sr_{3-x}Y_xCu_2O_8$ was studied in the range x = 0.3 to 1.0. The amount of Cu^{3+} increased with x, and at some value of x there is the appearance of superconductivity. A phase diagram was shown.

Professor Rao noted Indian work in the Bi and Tl compounds and stated that the copper gives no EPR signal in any compound. From photoemission studies a peak is suggested to arise from molecular oxygen. The importance of oxygen holes and Cu^{1+} ions in superconductivity was stressed.

Two additional short presentations were added by Professor P.T. Wu, Taiwan, and Dr. H. Ihara, Electrotechnical Laboratory (ETL). In the report by Wu superconductivity was determined by a four-contact resistivity measurement with a sensitivity of 10^{-6} ran. He also reported a tetragonal structure a=b=0.344 nm and c=3.95 nm in a P4/mcc structure. I have noted that he had not been able to reproduce a 160-K zero resistance and that the crystal structure was of the P4/mmm type. Other results for Tl were as follows:

a=b (Å)	c (Å)	Compound	Comment
3.85	79.1	1234	nearly single phase
3.85	22.3	1245	mixed phase
3.85	42.0	2234	insulator

No T_c higher than 122 K was found.

For Tl-Ba-Cu-Ar-O:

Composition T_c	Cu Planes (K)	n
1201	17	1
1212	91	2
1223	116	3
1234	122	4
1245	117	5

The copper valence was stated to vary as 2+1/n. The difference between the 1234 compound structure was stated to be significant by Wu; Ihara doesn't observe glide planes, but at this point it is up to Wu to provide additional evidence since ETL is one of several laboratories that have not reproduced the higher T_c. If the effect of W_{11} is really a surface phase (that would allow for no Meissner effect), then the structure of the bulk is not necessarily so important.

An interesting discussion of organic superconductors was given by Professor G. Saito. He discussed methods of preparation, resistivity measurements, and isotope effect of $(BEDT\text{-}TTF)_2Cu(NCS)_2$, with T_c between 10.4 and 11.0 K. An inverse isotope effect is found; deuterated samples have a higher T_c by about 0.5 K. Almost 100 percent diamagnetism was observed at 6 K. The upper critical field shows a crossover from 3D to 2D when the field is parallel to the 2D plane. The band structure shows a gap in one direction. The dc susceptibility is nearly constant between 90 and 300 K and metallic to 10 K. A decrease in T_c is observed under pressure. The plans are to obtain an organic superconductor with $T_c \sim 15$ K.

Some 120 posters dealt with other aspects of the science--these cannot be reviewed completely enough for inclusion here. The organizing committee gave first preference to industrial contributions so the criterion was not solely the scientific quality.

The conclusion from these discussions of experimental results is that very new studies continue to expand the variations in the four families of high temperature superconductors, and I would judge that other properties, such as magnetic properties, will also show a wide compositional range. The question of the copper valence and thus the role of oxygen holes is not fully settled. New results suggesting the need for small amounts of lead to stabilize the higher transition temperature phase in bismuth and thallium materials may be explored further; the addition of lead is in agreement with the "multiple element" remark of Dr. Cava.

MICROSTRUCTURE AND VORTEX PINNING

In this area several systematic studies, especially those of Professor J. Evetts, are beginning to suggest that better control of microstructure will be achieved and that the bulk critical current will be increased. Drs. H. Maeda, A. Kohno, and M. Murakami presented studies indicating compositional variations at grain boundaries in YBCO and calculations to indicate how initial design of magnets for the YBCO material might proceed.

The Cambridge work discussed by Professor Evetts drew analogy with the long-term learning curve to control microstructure in the A-15 materials and to determine the vortex pinning mechanism in Nb_3Sn. He noted the 37-percent volume expansion of the reacted zone in the bronze process that can both be a stress problem and a help in keeping brittle reacted material under compression and thus reduce cracking. The strain in Nb_3Sn must be kept to less than 2 percent to prevent a stress relief by a change of grain morphology (rather than cracking). The geometry of the filament cross section can be modified to advantage; elliptical is better in the high temperature superconductors. They are determining the mode of diffusion, the value D(T), the anisotropy, and the equilibrium stoichiometry. Different modes of diffusion are found at higher temperatures. The time to oxygenate a sample of different size at two selected temperatures is given for YBCO as follows:

	Time for Thicknesses of--		
Temperature (°C)	10 nm	100 μm	10 mm
400	50 ms	60 days	2000 yr
600	5 s	500 s	60 days

The time to deoxygenate was also noted. However, at high temperatures the high oxygen content needed for $T_c \sim 95$ K cannot be obtained with 1 atmosphere of oxygen, so they have applied up to 10,000 atm pressure of O_2. Too high a pressure does not result in better oxygenation.

An interesting aspect of Evett's work was the electrochemical results. Some 0.2 V was equivalent to 10^4 atm oxygen pressure, and he has substituted O, F, and Cu this way.

The lattice parameter changes of the high temperature superconducting materials were considered important since stress could drive out oxygen and the grain morphology and twinning depend on stress during diffusion. The presence of an insulating phase can be exploited--electrochemical substitution of Ho, Y; Ag, Cu; and F, O was noted. Finally, a stainless steel sheathed hollow core (for oxygenation) wire was fabricated, with a thin wrap of silver, 20 μm or so. Dr. Fluss, Lawrence Livermore National Laboratory, noted the large single crystals they have grown at the larger oxygen pressures, 3,000 atm, as another reason for developing high pressure oxygenation equipment.

Dr. Maeda described Toshiba results on the stabilization of a superconducting magnet. The larger specific heat of the superconductor and of any stabilizer at 77 K compared to 4 K is generally helpful in quench prevention. However, by itself the YBCO, because of the poor thermal conductivity, will have a very prompt temperature rise to room temperature in less than 1 ms, but with a silver stabilizer the room temperature is reached in 6 seconds. Thus, good sensors for quench and resistive shunts can be designed specially for this system. The normal zone propagation is low due to the low thermal conductivity.

Dr. Murakami described Nippon Steel Corp. efforts to determine critical current limitation, the source of the weak links. Better homogeneity gave increased j_c, from 5 to 700 A/cm^2. Bulk density increases with sinter temperature, but above 950 °C the j_c drops. A very nice mapping in two dimensions to about a 1-μm resolution with computer false color graphics revealed chemical inhomogeneity very easily. An EDS analysis at the grain boundary showed a lack of yttrium, so $BaCuO_2$ may be one cause of the weak link. The use of fine powder and low temperature sinter gave $j_c \sim 1{,}200$ A/cm^2, and no cracking or inhomogeneity at the grain boundaries was found. The magnetization showed no change with sample size so even clean grain boundaries may still act as weak links. Their best results were stated to be greater than 1,000 A/cm^2 at 10 T and 77 K from a peritectic reaction of Y_2BaCuO_5 (211) and liquid phases of CuO and $BaCuO_2$. Long plate shaped phases of 123 appeared in the 211 phase.

In Dr. Kohno's discussion on processing, he indicated that Fujikura is making significant progress in obtaining improved critical currents up to 1,900 A/cm^2 in the bulk with less than 1 hour annealing time. From the composition diagram the ratio of Ba:Cu of 3:5 was determined to match with a 211 composition to produce the 1,2,3 material. The lowest temperature for decomposition was 926 °C. The x-ray diffraction pattern for a process temperature of 950 °C shows the 1,2,3 phase. For wires a composite powder process was described, and after swaging and cold work the silver sheath is peeled off so the critical current of the high temperature superconducting material is measured directly. A j_c of 730 A/cm² occurs for a particular annealing time. Results were also stated for a vapor phase deposited tape conductor with a thickness of 1 μm. These results show considerable promise but also indicate that no significant step in bulk processing has yet been taken beyond the hard-to-reproduce textured growth by AT&T reported some time ago.

APPLICATIONS

In the area of applications the guarded optimism of the Japanese industries contrasts with the less optimistic view in the United States. Professor H. Hayakawa and Drs. S. Haruo and O. Kohno (already discussed) indicate continued and significant resources being directed toward eventual product development--Professor Tanaka noted to me during a visit that Furukawa now has 50 people working on high temperature superconductors with the realization that progress will take time.

These sessions were in parallel so that only an incomplete discussion of these application results can be provided.

Professor Hayakawa described the progress on Nb Josephson junctions, now reaching the LSI level, and the SIS mixer already important for astrophysics (work done, I believe, in the United States). A progression of line width size reduction was shown for DRAM (semiconductor) on a single chip:

1 Mbit 1.3 μm	current production
4 Mbit 0.8 μm	sample
16 Mbit 0.5 μm	under development

Concerns at present with semiconductors at smaller line widths are hot carriers and voltage breakdown. There is a move to lower temperatures such as 77 K in order to increase speed and packing density of semiconductor elements, for example, in the liquid nitrogen cooled computer ETA-10. Already the low frequency loss for YBCO is less than copper. Pulse transmission calculations show favorable low dispersion results for a 5-ps pulse over 1 cm. Thus a suggested plan is to integrate semiconductor memory with superconducting interconnects and digital processing. A question was asked as to whether optical connections might be better; it was noted that optical applications are important.

A review of superconducting electronic development was given by Dr. Hasuo, Fujitsu. The new result for 1988 is the development and test of a 4-K memory and testing the four-bit microprocessor developed last year. The four-bit processor is on a 5- by 5-mm square with 2.5-μm line and has over 5,000 junctions. It operates at a 770-MHz clock speed and consumes 5 mW as compared to a GaAs comparable system that runs at 72 MHz and consumes 2.2 watts. The memory is made with 4-μm line and has 14,468 junctions on a 7.8-mm square chip. The junction cell size is 83 by 83 μm. Access is 550 ps (not yet as fast as existing semiconductors). SQUIDs are presently used with 300 K electronics, so Fujitsu has developed a 4-K feedback circuit. At present the sensitivity is limited to 7 x 10^{-5} $\phi_0/\sqrt{\text{Hz}}$, the dynamic range is 100, and the slew rate is 3,000 ϕ_0/s. This sensitivity has not been measured yet in a shielded room. Their aim is to make a multi-SQUID single chip for medical use. For high temperature superconductors the voltage, current, and power loss would increase, but the switch time is expected to be about the same.

Plans were discussed in an overlapping session to build a 150-ton electromagnetic drive boat to test that principle. Conventional superconducting magnets will be used at first. Also a 50-km track is to be built for a new magnetically levitated train test to achieve 500 km/h operation--the present track is only 7 km and the imbedded loops are not optimum for the higher speed operation. These are both large-scale demonstrations that represent significant financial commitment. Professor S. Nakajima gave a plenary lecture on early developments where, in fact, his own theories played an important role and his subsequent influence on Japanese science for the development of superconductivity in Japan has provided a strong foundation on which the new effort is based. He noted challenges to be solved, the role of Cu-O layers, understanding the BiO_3 materials, and the complexity of materials and the relation to high j_c. He reflected on whether theoreticians were working too hard, noting all the various models that await careful experimental test. In order to support the commercialization of a wide range of products over a long-term period of time, basic studies with sustained funding are vital.

In the closing session speakers were asked to speculate about the future. Many items were restatements but some seemed noteworthy. Professor de Jongh's suggestion of Bose condensation and the role of fluctuations were discussed. Dr. D. Finnemore made a strong statement to define the terms so that flux expulsion, vortex motion, and vortex lattice melting can be clarified much as the development of H_{c1} and H_{c2} needed definition in type II superconductors. Professor G. Zimmerman noted a magnetic current transfer idea where induced current, loop-to-loop, is transferred; the loops can be made flexible one to another even though each loop is not flexible. He has tested the idea in conventional superconductors and affirms nearly full critical current and operation up to several hundred hertz.

CONCLUDING REMARKS

A statement made by Professor T. Kobayashi bears repeating--to realize practical application of new concepts a technology base must be developed. The Japanese plan of ISTEC with 45 companies pooling their efforts will go a long way toward the development of such a base; the plan to make ISTEC international is to be commended in this author's view. If this symposium is an example, ISTEC is off to an excellent start.

Donald H. Liebenberg received B.S., M.S., and Ph.D. (1971) degrees from the University of Wisconsin in physics. A staff member at Los Alamos National Laboratory for 20 years until 1981 he carried out research in the areas of low temperature physics, high pressure physics, and solar physics and contributed to major Laboratory programs such as Rover (the cryogenic fluid propellant nuclear rocket reactor) and the laser fusion program where he was on the technical staff of the project director's office. Some 100 technical publications resulted from these investigations including the first application of fluctuation theory to the problem of superfluid helium film flow, the determination of the solar coronal temperatures and line-of-sight turbulence structure from precision spectroscopic measurements, and the initial studies of gases at high pressures in a diamond anvil cell. As Program Director for Solar Terrestrial Physics (on rotation to the National Science Foundation in 1967-68) and later as Program Director for Low Temperature Physics (1981-88) he was instrumental in obtaining submillikelvin research support and facilities and in supporting high temperature superconductivity discovery research. He joined the Office of Naval Research, Physics Division, in 1988 as Scientific Officer in Condensed Matter Physics. Dr. Liebenberg is a member of the American Physical Society, American Astronomical Society, American Geophysical Union, American Association for the Advancement of Science, and the Cosmos Club of Washington.

A NAVIER/STOKES BENCHMARK FOR JAPANESE AND U.S. SUPERCOMPUTERS

K. Fujii and H. Yoshihara

Results of a recent benchmark for single-CPU Japanese production supercomputers on the unsteady Reynolds-averaged Navier/Stokes code are given. Supercomputers used were the Fujitsu VP-400E, the Hitachi S-820/80, and the NEC SX-2A. The multiple-CPU Cray Y-MP/832 was also benchmarked. The calculations were carried out for a strake-delta wing at M = 0.3° and 12° angles of attack. A common mesh was used with about 850,000 mesh points.

INTRODUCTION

Results of a recent Navier/Stokes benchmark are given for current production supercomputers. The primary focus was on the single-CPU Japanese supercomputers, the Fujitsu VP-400E, the more recent Hitachi S-820/80, and the NEC SX-2A. The multiple-CPU Cray Y-MP/832 was also benchmarked. (Note: 832 = 8 CPU + 32 megawords of memory.) ETA Inc. was unable to participate at this time. The calculations were carried out by computer company personnel over the 3-month period 15 October 1988 to 13 January 1989.

Objectives of the benchmark were twofold: (1) to measure the performance of the supercomputers for a typical flow problem using the unsteady Reynolds-averaged Navier/Stokes code, a key aerospace design tool for the coming decade, and (2) to evolve guidelines for the tuning of the compiler and programming to give optimal machine/code compatibility by specialists familiar with the computer architecture.

The Navier/Stokes procedure selected was the Fujii/Obayashi code (Ref 1)*, representative of the compressible Navier/Stokes codes in use in the United States and Europe. The benchmark problem was for the subsonic, high-lift flow over a strake-delta wing considered earlier (Ref 2)**.

Three cases were calculated using the same mesh as follows:

1. Calculations with the code as furnished using the standard compilers. For the Cray Y-MP/832 calculations with both one and eight CPUs using the autotasker in the latter. (Autotasker seeks to distribute automatically and optimally the workload to the CPUs at the subroutine to DO-loop levels.) (200 iterations)

*1. K. Fujii and S. Obayashi, "Use of high-resolution upwind scheme for vortical flow simulation," AIAA Paper No. 89-1955.

**2. K. Fujii and L. Schiff, "Numerical simulation of vortical flows over a strake-delta wing," AIAA Paper No. 87-1229 (to appear in the *AIAA Journal* in 1989.)

2. Calculations using the code as furnished, but permitting additional Fortran-compatible compiler tuning including use of compiler directives. (200 iterations)

3. Calculations same as Case 2, but modifications of the algorithm and changes in the programming additionally permitted. (200 and 2,000 iterations, latter to measure the convergence)

Benchmark participants were as follows:

- Mr. K.P. Misegades, Manager, CFD Applications Group, Cray Research Inc., Mendota Heights, MN 55120. (Dr. T. Saito, Cray Research Japan, Inc. assisted in the benchmark.)

- Mr. N. Tahara, Manager, Scientific Applications Section, Mr. M. Amakai and Dr. M. Makino, Supercomputer Applications Section, Fujitsu Ltd., 1-17-25, Shinkamata, Ota-ku, Tokyo 144.

- Mr. S. Kawabe, Senior Engineer, and Mr. K. Ishii, Computer Development Dept., Hitachi Ltd., 1 Horiyamashita, Hadano-shi, Kanagawa-ken 259-13.

- Mr. S. Mineo, Supervisor, 3rd Systems Support Dept., NEC Corp., 2-7-17 Shiba, Minato-ku, Tokyo 105.

In the next sections, the CPU and elapsed times for the three cases are given together with brief comments on the results. This is followed by concluding remarks. In the Appendix, details of the Fujii/Obayashi Navier/Stokes code and the delta wing problem are given together with a summary of the relevant computer architectural features.

BENCHMARK RESULTS

The CPU and the elapsed times for the three cases are given in alphabetical order.

Computer	CPU (min)	Elapsed (min)	CPU/ Elapsed
Cray Y-MP/832			
1: (200 iter./1 CPU)	57.57	57.58	1.00
(200 iter./8 CPU)	66.42	46.37[a]	1.43
2: (200 iter./8 CPU)	52.22	7.97	6.93
3: (200 iter./8 CPU)	55.07	8.15	6.76
(2,000 iter./8 CPU)	550.4	77.92	7.06
Fujitsu VP-400E[b]			
1: (200 iter.)	25.51	28.17	0.91
(2,000 iter.)	254.60	258.41	0.99
Hitachi S-820/80			
1: (200 iter.)	16.75	17.80	0.94
3: (200 iter.)	16.32	18.43	0.89
(2,000 iter.)	161.98	163.63	0.99
NEC SX-2A			
1: (200 iter.)	24.33	24.79	0.98
3: (200 iter.)	20.12	20.52	0.98
(2,000 iter.)	200.80	201.20	1.00

[a]This autotasker anomaly was circumvented by directives in Case 2.
[b]No changes were found to be necessary in Cases 2 and 3.

The computational speed actually attained is a measure of performance of interest and is obtained by dividing the total operation count of the calculation by the CPU time. In Case 1 (200 iter.) the operation count was obtained from the measured performance of the Cray Y-MP where an actual speed of 0.175 GFLOPS was achieved with a CPU time of 57.57 minutes. Based on this operation count, the actual speeds of the computers were as follows:

Computer	Peak GFLOPS	Actual GFLOPS	Actual/ Peak
Cray Y-MP/832	0.334	0.175	0.524 (2)[a]
Fujitsu VP-400E	1.7	0.395	0.232 (12)
Hitachi S-820/80	3.0	0.602	0.201 (12)
NEC SX-2A	1.3	0.414	0.319 (8)

[a]Number of independent add or multiply pipes.

The actual speeds achieved relative to the peak speeds for the one-CPU computers were relatively low in the above case. There are several causes. First and probably the dominant cause was the inadequate "vector length per pipe" in the DO-loops leading to lowered pipe efficiencies through the increased role of the pipe fill-in overhead. Here the vector length in the DO-loops was at most the product of the two largest mesh dimensions, which in the present benchmark was of the order of 10^4. The difficulty is that this vector length is partitioned over each of the independent pipes, and this greatly reduces the "vector length per pipe" for the computers with a large number of pipes. The second cause was the interruptions in the "CPU flow" due to subroutine calls and nested DO-loops which the autovectorizers cannot routinely eliminate. In some cases inadequate number of paths and bandwidths between memory and register also contributed to the increase of the time.

In the present benchmark the Cray Y-MP/832 largely avoided the above shortcomings of the single-CPU computer by using the autotasker and directives to maximize the use of the multiple CPUs. Thus autotasking directives were used to parallelize independent subroutines. Outermost loops were also effectively parallelized with directives, greatly increasing the granularity (degree of parallelization.) The net result was a remarkable parallelization of 98.8 percent of the maximum possible (Amdahl value) achieved by the Cray autotasker implemented by four autotasking directives. Thus, with eight CPUs the Y-MP calculated the benchmark problem with an elapsed time that was 88.3 percent of the single-CPU elapsed time divided by 8.

Also notable in the above results was the 21-percent improvement in the elapsed time in Case 3 relative to Case 1 for the NEC SX-2A. This was accomplished by an in-line expansion of two time-consuming subroutines and unrolling of outer DO-loops to increase the vector lengths of the inner loops in strategic nested loops. These improvements increased the actual/peak speed ratio to 0.385 from 0.319 previously listed. (The above improvements could also have been made in the other computers.)

CONCLUSIONS

Notable findings specific for the present benchmark were as follows:

1. In the single-CPU computers, the impressive high speed of the processors cannot be fully used unless the "vector length per pipe" is sufficiently large. Despite the near-100-percent vectorization ratio, subroutine calls and nested DO-loops can significantly degrade the actual/peak speed ratios.

2. The Cray Y-MP/832 computer circumvents the above performance shortcomings of single-CPU computers through the indispensable flexibility offered by parallelization. When implemented with four directives, the autotasker performed with an impressive 98.8-percent efficiency in the present benchmark.

3. The actual/peak speed ratios of all CPUs can be significantly reduced simply by the actual peak speed of the add and multiply pipes being much lower than that defined in terms of the clock cycle time. Thus, for example, in the case of the Hitachi S-820, the actual peak speed is 2 GFLOPS compared to the rated 3 GFLOPS.

Finally one is reminded of the perishability of supercomputer benchmarks. Improved performance can be expected in the forthcoming Fujitsu VP-2600, Cray 3, and the

NEC SX-3. The Navier/Stokes benchmark for the Fujitsu VP-2600 with a processor speed of at least 4 GFLOPS is planned for the summer of 1989, while that for the 4 CPU (22 GFLOPS) NEC SX-3 is scheduled for spring 1990. Introduction of the 16-CPU Cray 3 with gallium arsenide chips (2 ns cycle time) and a total processor speed of 16 GFLOPS is scheduled for late 1990.

It is clear that for the present benchmark problem, increasing the power in single-CPU machines may simply worsen the actual/peak speed ratios unless accompanied by significantly improved compiler software and a major code restructuring. For multiple-CPU computers, it is not clear how far the parallelization efficiency can be maintained with increasing number of CPUs. Multiple-instruction-path computers have, however, the option to use as many CPUs as can be used efficiently, time-sharing the remainder.

The benchmark further addressed one approach to reduced computing time, namely, through improvement of the code/software/architecture compatibility. Potentially much greater payoff is offered by algorithm improvements that accelerate the extremely slow convergence of the Navier/Stokes solution. Moreover, algorithms, other than ADI factorization, should be considered to increase the vector lengths.

ACKNOWLEDGMENTS

The authors wish to express their appreciation to the benchmark participants listed earlier and to the managements of Cray Research Inc., Fujitsu Corp., Hitachi Corp., and NEC Corp. for making the benchmark possible. Much of the material contained herein was extracted from reports submitted by the benchmark participants.

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Hideo Yoshihara arrived in Tokyo in April 1988 for a 2-year assignment as a liaison scientist for the Office of Naval Research. His assignment is to follow the progress of advanced supercomputers and to review and assess the viscous flow simulation research in the Far East. Dr. Yoshihara formerly was with the Boeing Company, where he was Engineering Manager for Applied Computational Aerodynamics. He was also an affiliate professor in the Department of Aeronautics and Astronautics of the University of Washington, an AIAA Fellow, and a former member of the Fluid Dynamics Panel of AGARD/NATO.

FUJII/OBAYASHI NAVIER/STOKES CODE (Ref 1)

The Fujii/Obayashi code is a finite difference procedure in the delta formulation for the unsteady Reynolds-averaged Navier/Stokes equations with the Baldwin/Lomax algebraic turbulence model. The equations are solved in a time-asymptotic fashion using an LU-ADI factorization algorithm. The Beam/Warming approximate factorization is employed to simplify the difference operator to a product of three alternating direction operators. With a diagonalization transformation each 5x5 block tridiagonal matrix is reduced to a set of five scalar tridiagonal matrices. Each diagonalized operator is then decomposed into two operators using flux vector splitting (approximate LU factorization). In the solution process, an inversion in one direction consists of one scalar forward sweep and one scalar backward sweep. The operator in each direction can be considered as a single iteration of a symmetric Gauss/Seidel relaxation in one dimension. For the spatial discretization Roe's flux difference splitting is used for the evaluation of the steady-state convective terms. Higher order extension is realized by the MUSCL interpolation method. Programming of the code was guided by the requirement of good maintainability and portability. Thus vectorization was limited to the inner loops avoiding code restructuring that would degrade the above properties.

BENCHMARK FLOW PROBLEM

The flow calculated was for a strake-delta wing (80° strake sweep/60° wing sweep) at a Mach number of 0.3, an angle of attack of 12°, and a Reynolds number based on root chord of 1.3 million. The mesh dimensions were 119 points in the chordwise direction, 101 points on the half-circumference, and 71 points in the radial direction for a total of about 850,000 mesh points. This mesh was selected to allow calculations using only the main memories.

COMPUTER HARDWARE CHARACTERISTICS

Hardware features that affect the execution time are next given. The clock cycle time and peak CPU speed are given below. Here the CPU speed in GFLOPS is defined by the number of independent add and multiply pipes divided by the clock cycle time in nanoseconds. (It should be noted that the actual peak speed may be significantly different from this definition.)

Computer	Clock Cycle Time (ns)	Peak Speed (GFLOPS)
CRAY Y-MP/832	6.4	2.5
Fujitsu VP-400E	7.0	1.7
Hitachi S-820/80	4.0	3.0
NEC SX-2A	6.0	1.3

The capacity (in megabytes) of the main memories is as follows:

Computer	Capacity (MB)
Cray Y-MP/832	256
Fujitsu VP-400E	1,024
Hitachi S-820/80	512
NEC SX-2A	1,024

Below the number of read and read/store pipes connecting memory and vector registers together with the corresponding total bandwidths in gigabytes per second are given. For highly vectorized codes, the memory/register bandwidth should be sufficient to keep the CPUs operating full time.

Computer	No. of Pipes	Total Bandwidth (GB/s)
Cray Y-MP/832	4/CPU	42.7
Fujitsu VP-400E	1	5.57
Hitachi S-820/80	8	16
NEC SX-2A	1	11

JAPANESE NATIONAL RESEARCH INSTITUTE FOR METALS

F.S. Pettit

The National Research Institute for Metals (NRIM) is one of the important research organizations in Japan. Its research is concerned with materials fundamentals, materials processing, and materials reliability. Special emphasis has been placed upon research involving intermetallic compounds, advanced powder processing, materials life prediction, nuclear reactor materials, and superconducting materials. This institute is attempting to change the character of its research from industry-oriented applied research to more long term fundamentally oriented research. The organization of NRIM is described and examples of the research being performed in all of the research divisions and groups are presented.

INTRODUCTION

The National Research Institute for Metals (NRIM) was established in July 1956 as a research organization attached to the Science and Technology Agency (STA) of the Japanese Government. The organizational relationships in regards to NRIM and other research organizations in Japan are presented in Figure 1. NRIM was formed 1 year after the National Aerospace Laboratory and was put under STA because of the need for new alloys for aerospace needs. Its annual budget for 1988 was $42,000,000. The proposed budget for 1989 is $46,400,000. These funds include personnel, facilities, and research projects. NRIM currently has 434 employees of which 332 are research staff. Since 1985 NRIM along with other government agencies has been required to decrease its staff. This has been done through retirements and involves a few persons per year. For example, NRIM had a total staff of 447 in fiscal year 1985.

The initial objectives of NRIM, as well as most other Japanese scientific and technical organizations and institutions, were to strengthen Japanese industry. Therefore, much of the research was intentionally applied in character and directed toward industrial applications. The Japanese now believe the most important need is to develop and strengthen creativity and innovation. Many research institutions in Japan, including NRIM, thus have new objectives, namely, more fundamental and longer term research. The emphasis on creativity and fundamental research was implemented in fiscal year 1987. Progress has been slow because personnel changes are via attrition only. Consequently, the same staff, who previously had worked for years with engineering applications at the forefront of their efforts, must now acquire different views as to what is important.

NRIM has an advisory committee and visiting research officers. The advisory committee is composed of authorities largely from universities, industry, and a few government organizations. This committee meets once a year to give formal approval to the NRIM technical program. Visiting research officers are used to establish within NRIM expertise that is viewed critical but not available within the permanent NRIM research staff. These visiting scientists come from industry or universities.

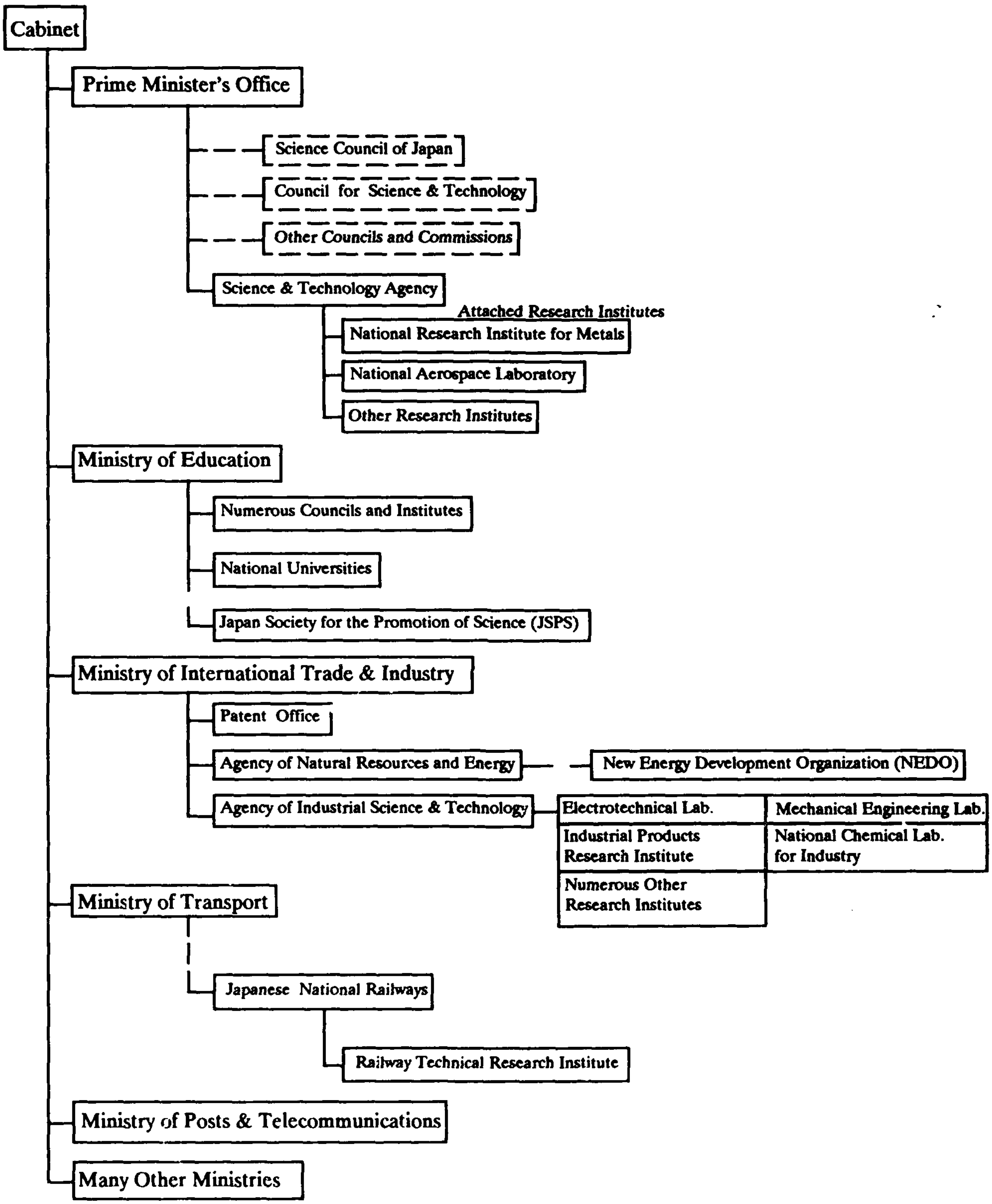

Figure 1. Administrative structure of science and technology in Japan.

In an attempt to develop more long term research capabilities, as well as in response to the need to emphasize investigations on a number of critical technical topics, NRIM was reorganized in 1988. The current organization is described in Figure 2. The new organization consists of 10 research divisions and 5 research groups. A research division is more permanent than a research group. Research groups are evaluated regularly, at least once every 5 years, and the research thrusts in a group may be continued or terminated. The research at NRIM consists of thrusts, as described in Figure 2, in three critical areas of materials, namely, materials fundamentals, materials processing, and materials reliability. As has been the case of most metals-based institutions and organizations, NRIM's research, while still emphasizing metals, can be more succinctly described as materials research.

NRIM's facilities are located in Tokyo and in Tsukuba City, which is about 30 miles outside of Tokyo. Within 5 years the entire effort will be located in buildings that are being constructed in Tsukuba City. The Mechanical Properties Division and the two research groups now at Tsukuba perhaps could be considered part of the three thrust areas, but at present they are just considered part of the Tsukuba Laboratories effort. The equipment available for research at NRIM is modern and covers a wide range, from characterization to testing of materials. Facilities to fabricate materials using new techniques are abundant The physical plant at the Tokyo site is old. In the following parts of this paper research being performed in the three thrust areas and at the Tsukuba Laboratories will be described sequentially.

MATERIALS FUNDAMENTALS

The materials fundamentals thrust consists of research in four divisions, namely, the **Materials Physics Division**, the **Physical Properties Division**, the **Materials Design Division**, and the **Materials Characterization Division.**

Some of the current research themes in the **Materials Physics Division** are:

- Computer Simulation of Growth Processes in Artificial Materials (T. Oguchi)
- Physical Properties of Rare Earth Compounds (T. Matsumoto)
- Electrical Conductivity and Surface Activity of Solids (M. Ohkouchi)
- Influence of Alloying Element Partition Upon the Kinetics of Diffusional Phase Transformations (M. Enomoto)
- Synthesis and Physical Properties of Highly Correlated Electron Systems (H. Aoki)
- Computer Simulation of Solid-State Processes for Fabrication of Amorphous Materials (K. Kusunoki)

A few specific examples of research in the Materials Physics Division are described in the following.

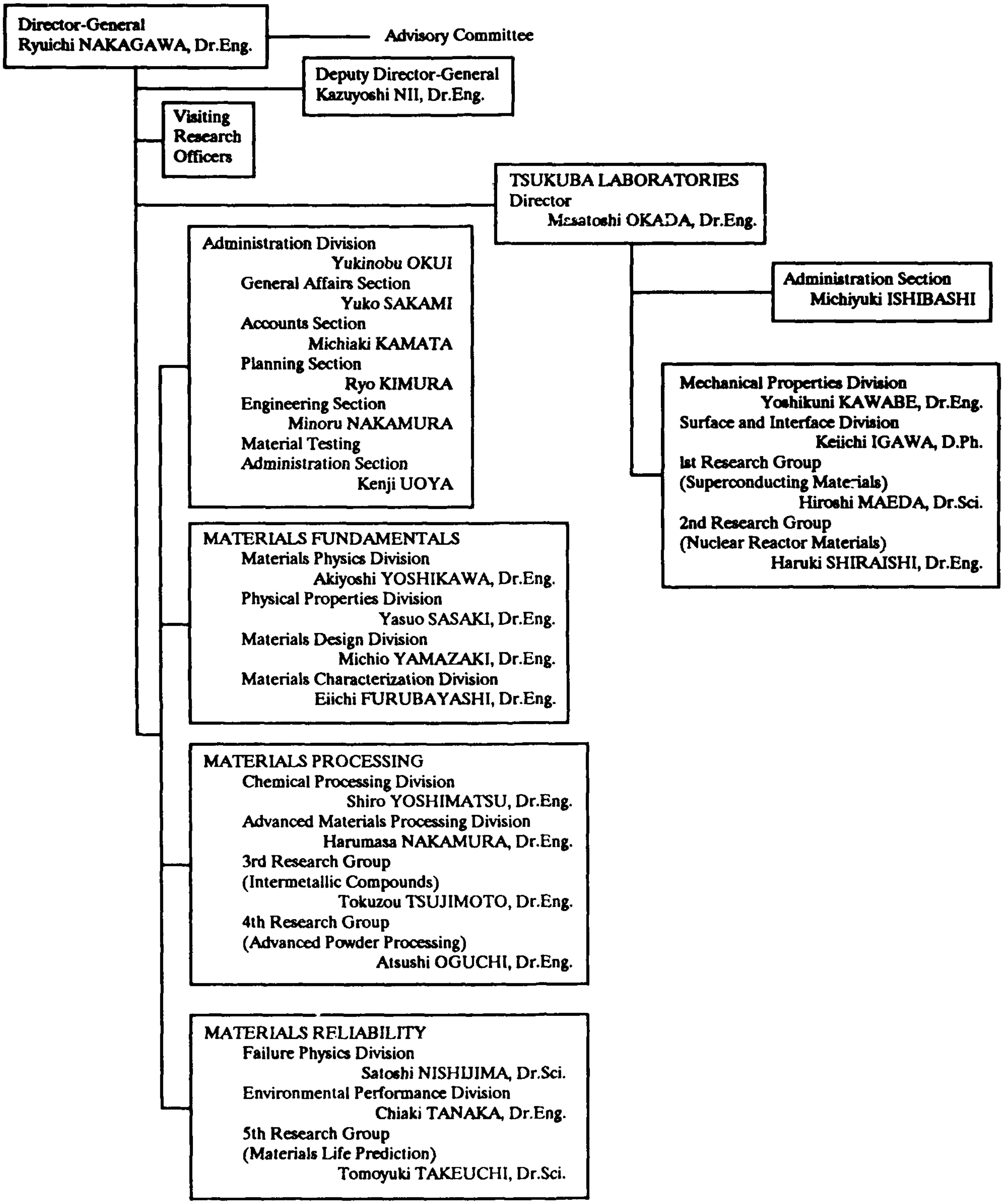

Figure 2. Organizational structure of the National Research Institute for Metals.

Magnetic fluids can be used in the direct conversion of thermal energy to kinetic energy where the working fluid is the magnetic fluid itself. Colloidal fine particles of Fe, Co, and Ni were prepared by evaporation onto the surface of a liquid using a rotating vacuum chamber (Ref 1). The liquid was a hydrocarbon oil (alkylnaphthalene) and a surface-active agent (polybutenylsuccinpolyamine). Crystalline particles about 20 Å in diameter were identified with no aggregation. Magnetization was measured in magnetic fields up to 15 kOe at temperatures from 4.2 K to room temperature. In the case of Fe and Co the particles were superparamagnetic above 80 K. The nickel particles were superparamagnetic above 40 K. The saturation magnetizations, normalized by the saturation magnetization of the bulk metals at 0 K, were determined from 4.2 to 300 K. This ratio was close to unity at 4.2 K in the case of Fe and Co but 0.5 for Ni. It was proposed that the magnetic moment in the surface layer of the particles was affected by adsorbed molecules of the surface-active agent.

Enomoto has worked with Aaronson at Carnegie Mellon University to study a number of phenomena occurring during the nucleation of ferrite in Fe-C-X alloys where X was Mn, Ni, Co, or Si (Ref 2,3). In particular, the displacement of the capillarity-corrected nucleus composition of ferrite from the bulk equilibrium composition was evaluated. The nucleation kinetics of ferrite at austenite grain boundaries and the effects of grain edges versus grain faces were compared. Edge nucleation was appreciable at small undercoolings and face nucleation became preferred as undercooling was increased. The results were dependent upon the prior austenite grain size in that at smaller grain sizes the temperature range for which edge nucleation predominated over face nucleation was larger.

The current research themes in the **Physical Properties Division** involve:

- Shape Memory Effects in Steels and Its Application (S. Kajiwara)
- Manganese-Based Damping Alloys (K. Kawahara)
- Synthesis of Optical Memory Alloys (H. Sasno)
- Synthesis and Properties of Ultra-Thin Fibers of Metals (I. Nakatani)
- Special Properties by Using Compositional Gradients (I. Shiota)
- Metallic Membranes for Hydrogen Separation (M. Amano)

Amano and coworkers (Ref 4) are investigating alloys for hydrogen storage. Intermetallic compounds such as FeTi and $MnNi_{5-x}Al_x$ are being examined to attempt to achieve improved hydrogen purification, heat storage, chemical heat pumps, and rechargeable hydride electrodes. Nakamura (Ref 5) has investigated the thermodynamic properties of hydrogen solution in amorphous Fe-Ti (43-60 at. % Ti) films prepared by magnetron sputtering. The pressure-composition isotherms show positive deviation from Sievert's [illegible] concentration of hydrogen proportional to the square root of the hydrogen pressure), which indicates that hydrogen atoms occupy interstitial sites. The relative partial molar enthalpies derived from the isotherms decrease with increasing hydrogen concentration and in dilute concentrations are about three times larger than that for formation of monohydride in crystalline FeTi. The anomalously large relative partial molar enthalpies for hydrogen dissolution in amorphous Fe-Ti indicate that the local environment around the hydrogen atoms is different from that in crystalline FeTi.

Sasano and Suzuki have investigated the influence of strain-thermal cycles on the fatigue of shape memory TiNi helical springs. It has been observed that the deterioration in shape memory properties is not affected by the phase transformations under stress free conditions, but deterioration of shape memory properties does occur when the transformations take place at high applied stress.

The ultimate goal of the **Materials Design Division** is to be capable of specifying the compositions and processing conditions necessary to fabricate materials with certain specified properties. Some specific research themes currently active in this division are:

- Systemization of Knowledge for Designing Materials (K. Hashimoto)

- Improvement of Durability of Tungsten Fiber Reinforced Superalloys (T. Arai)

- Advanced Alloys with Controlled Crystalline Structures (M. Yamazaki)

- Knowledge Base System for Computer Aided Chemical Substance Design (M. Yamazaki)

- Physical, Chemical, and Biological Phenomena Under Microgravity Environment (M. Yamazaki)

Yamazaki and coworkers have been working very intensively on the design of nickel-base superalloys and titanium alloys (Ref 6-8). In the case of nickel-base superalloys, a series of equations for γ and γ' phases has been established by regression analyses using data generated by microprobe analyses of 30 experimental or commercial alloys and data from the Ni-Al phase diagram. By using these equations equilibrium γ and γ' compositions at a fixed temperature can be determined for various alloys extending from binary Ni-Al to multicomponent alloys containing Ni, Co, Cr, Mo, W, Al, Ti, Nb, Ta, Hf, and Re. These compositions can be selected to insure the absence of deleterious phases such as sigma, to fix the volume fraction of γ' phase in γ, and to control the lattice parameters of the γ' and γ. This procedure permits alloy compositions to be selected for further experimental testing and rejects those compositions that will have undesirable properties. This design procedure based upon alloy composition also permits certain properties to be estimated such as density, creep rupture life, and hot corrosion rate. Good agreement has been obtained between calculated and experimental values. By using these procedures new alloys have been developed that are competitive with current superalloys fabricated via conventional casting, directional solidification, single-crystal processing, and oxide dispersion strengthening techniques (Figure 3).

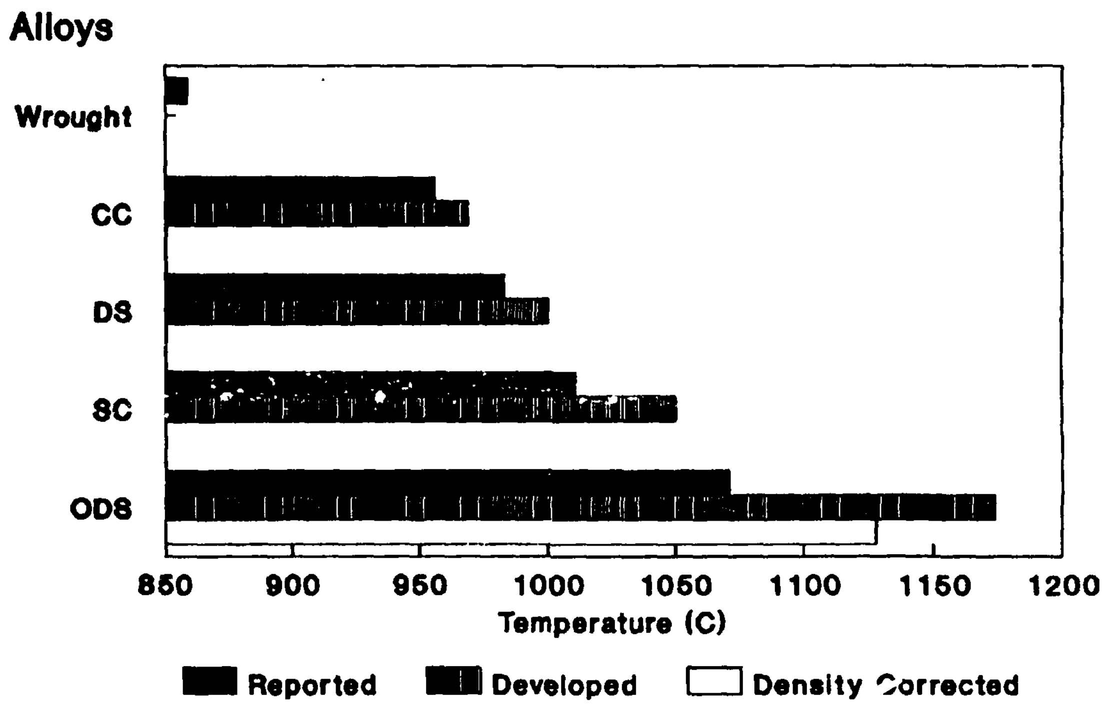

Figure 3. Temperature capability to give 1,000-hour stress rupture life at 14 kgf/mm^2. The wrought alloy is Udimet 500. The conventional cast, directional solidified, single-crystal, and oxide-dispersion-strengthened alloys used as reference systems (reported) were Mar M 247, Mar M 247DS, PWA 1480, and MA 6000, respectively. The NRIM developed alloys have the designations TM-321 (CC), TMD-5 (DS), TMS-12 (SC), and TMO-2 (ODS). The density corrected value is for TMO-2 (ODS).

While the approach described above works, the calculations to determine property values are empirical and the results must be used with care. For example, hot corrosion rates were determined based upon penetration depth in a burner rig test at 850 °C and were normalized by taking the rate for IN 738 as unity. Hot corrosion degradation of most nickel-base superalloys usually is characterized by an initiation stage and a propagation stage. In the initiation stage the alloys behave much as if the molten deposits were not present. In the propagation stage these alloys are very severely degraded, and the rates are so large that the difference between most superalloys is not significant. Consequently, the important parameter in describing the resistance of superalloys to hot corrosion is not a rate but rather the time required to initiate attack.

A design procedure has also been developed for titanium-base alloys. It is similar to that for nickel-base alloys. Since the fabrication and machining costs of titanium-base alloys are high, superplastic forming was planned to reduce fabrication costs. The objective, therefore, was to obtain superplastic alloys with improved strength-to-density ratios. Optimum superplastic behavior is obtained in titanium-base alloys when the microstructure is fine, equiaxed, and composed of approximately equal volume fractions of the α and β phases. The strength of α-β titanium alloys, however, is affected by both the compositions and volume fractions of these two phases. It is therefore necessary to calculate compositions and volume fractions of α and β phases at a given solutioning temperature in multicomponent alloys (Ti, Al, Sn, Zr, V, Mo, Cr, Fe). Such calculations have been done by using three methods. One method (A) was based upon Ti-X (X=Al, Sn, Zr, etc.) binary phase diagrams and was only a rough approximation because the interactions among solute elements were not considered. Another method (B), using actual, experimentally determined compositions of the phases, was used to develop equations consistent with the experimentally observed partitioning of various elements between the α and β phases. The third method (C) involved calculating compositions based upon a subregular solution model (Ref 9) and using data in the literature to estimate the necessary interaction parameters. Good agreement between calculated and experimental values was obtained for method B, but this method was only applicable for compositions near those used in the regression analysis. Method C was used for alloys containing eight elements. It gave good agreement between the calculated and observed volume fractions of α phase. Furthermore, this method accounted for the partitioning of elements between the α and β phases; however, the calculated partition ratios for some elements differed from those determined experimentally.

The Materials Characterization Division emphasizes analytical methods for determining ultralow concentrations of alloy constituents. Special emphasis has been placed upon rare metals, metal matrix composites, intermetallic compounds, and new metallic materials. Some current research themes are:

- Analytical Methods Concerned with Phase Transformations in Steels (E. Furubayashi)

- Evaluation of Machinability of High Hardness Materials (H. Nakajima)

- Elemental Factors Affecting Hydrogen Attack of Low Alloy Steels (H. Nakajima)

- Computer Image Processing in Electron Micro-Analysis (M. Fukamachi)

- Elemental Processes of Fracture in Metal Matrix Composites (C. Masuda)

- Development of Chemical Instrumentation by Using Plasmas (M. Saito)

- Elemental Analyses Developed for New Metallic Materials (H. Ohkouchi)

Saito and Sudo (Ref 10) have used isotope dilution spark source mass spectrometry to determine sulfur at 0.1 ppm levels in iron and iron alloys. Sulfur was precipitated as barium sulfate after dissolving the specimen in a HCl-HNO_3-$KClO_3$ solution. A spike solution prepared by dissolving elemental ^{34}S with nitric acid and potassium chlorate was also added to this solution. This precipitate was mixed with high purity gold powder (for specimens containing less than 0.0005 mass % sulfur) or graphite powder and pressed into electrodes. The relative intensities of the spectra ^{32}S and ^{34}S isotopes were calculated by the Churchill two line method using ^{194}Pt and ^{196}Pt isotopes.

MATERIALS PROCESSING

The materials processing thrust is composed of the **Chemical Processing Division**, the **Advanced Materials Processing Division**, the **Intermetallic Research Group**, and the **Advanced Powder Processing Group**.

Some of the research themes currently under investigation in the **Chemical Processing Division** are:

- Kinetics of Processes Related to Continuous Steel Making (A. Fukuzawa)
- Synthesis and Mutual Separation of Metal Chlorides (K. Kamiya)
- Production of Advanced Powders (A. Oguchi)

Asano et al. (Ref 11) have investigated the effects of deposition parameters on the synthesis of Nb_3Ge in a chemical vapor deposition (CVD) process using $NbCl_5$ and $GeCl_4$ gases as raw materials. The Nb_3Ge was formed on a Hastelloy-X tape at a temperature of 1,143 K. This tape was maintained at 1,143 K by its position in an electric furnace and additional resistive heating using a dc current. The composition of the deposited alloy, and hence its critical temperature to exhibit superconductivity, was shown to be affected by the composition of the gas, the geometry of the tape, and the temperature of the electric furnace. Curves relating the critical temperature of the deposit to furnace temperature and gas compositions were determined.

The **Advanced Materials Processing Division** is involved with using new processing techniques such as rapid solidification, high energy beams, and different thermomechanical treatments to develop new materials with unique properties. Some research themes that are being pursued in this division are:

- *Preparation and* Property Characterization of Refractory Metal Single Crystals (T. Fuji)
- Metal Processing Using High Energy Beams (H. Irie)
- Unidirectional Solidification Technology (A. Sato)
- Rapid Solidification Technology (E. Omori)
- Elemental Reactions in Interface Joining (K. Sasabe)
- Coatings Formation Via Deposition of Molten Metals (S. Kuroda)
- Incorporation of Solid Particles Into Metals During Solidification (T. Dendo)

Namai, Osawa, and Kikuchi (Ref 12) have dispersed particles of Al_2O_3, SiC, and graphite in aluminum and copper alloys. Molten alloys were atomized by using a gas atomizing apparatus and then particles of SiC, Al_2O_3, or graphite were mixed with the molten droplets prior to deposition in a mold. Uniform distributions of the particles in the atomized alloys were obtained. The volume fractions of the particles in the atomized alloys ranged between about 15 and 40 percent depending upon the particle size. As the particle size increased, the volume fractions were higher. Elements such as Ca in aluminum, and Ti in copper, were observed to cause an increase in the volume fractions of particles.

The **Research Group on Intermetallic Compounds** is concerned with taking advantage of the many very useful properties of intermetallic compounds. Some of the research being performed in this group is as follows:

- Development of Light Heat-Resisting Materials Based on the Intermetallic Compound TiAl
- Combustion Synthesis of Intermetallic Compounds (Y. Kanda)
- Intermetallic Compound Coatings for High Corrosion Resistance (A. Takei)
- Development of High Performance Thermoelectric Intermetallic Compounds (I. Nishida)

Tsujimoto and coworkers (Ref 13-15) are investigating the effects of third element additions to TiAl and to compositions on either side of the stoichiometric composition. Four factors are considered important for improving the ductility of TiAl alloys containing a third element: (1) increasing fineness of the microstructures, (2) an increase of annealing twins in the TiAl phase, (3) a decrease in the amount of the Ti_3Al phase, and (4) decreasing the Al concentration in the TiAl phase. Table 1 describes the microstructures of some of the alloys studied, and in Figures 4 and 5 some mechanical properties for these alloys at room temperature are presented. Mn and V at concentrations of about 2.5 at. % improve ductility in TiAl-Ti_3Al two-phase mixtures. In the case of Zr the ductility was not improved, but the strength at failure was increased. For single-phase TiAl alloys containing about 5 at. % Nb the ductility was also improved. These results have been interpreted by comparing third element sizes and the positions occupied by such elements in the crystal structure. Elements that improve ductility of TiAl are proposed to be those that are smaller in atomic size than both Ti and Al and occupy Al sites in the crystal structure. In TiAl, Zr and Nb substitute for Ti, Mn for Al, and V can occupy either type of site. Recently, NRIM announced the development of a titanium-aluminum alloy that features a high elongation. This alloy achieves this property by replacing some of the aluminum with manganese and has an elongation of 3 percent even at temperatures below 800 °C.

The oxidation resistance of TiAl is believed to be satisfactory up to 800 °C, but at 900 °C and above substantial amounts of oxidation occur. Without further alloying coatings will be required at 900 °C and above. Takei and coworkers are examining coatings for use on titanium-base alloys. Alloys with low aluminum concentrations (Ti-6Al-4V) have been aluminized by using a pack cementation process. Cyclic oxidation tests, at 1,073, 1,173, and 1,273 K, of the coated specimens showed that such coatings provided protection as long as a $TiAl_3$ phase was present in the coating. This phase was removed rather quickly (~25 hours) from coatings tested at 1,273 K. Longer times were required for the removal of this phase at the two lower temperatures; coatings were still protective after 40 hours at 1,173 K and 165 hours at 1,073 K.

The **Advanced Powder Processing Research Group** attempts to control the shape, size, structure, and compositions of powders in ways that permit the synthesis of new materials possessing unique properties. Some current research projects are:

Table 1. Summary of Microstructures and Crystal Lattice Parameters of TiAl-Base Alloys Annealed at 1,273 K for 605 ks and the Variation of These Characteristics with Alloying of Third Elements (after Ref 14)

Alloy Series (wt. %)	Third Element	Phases	Microstructure: Volume of α_2[a] (%)	Microstructure: Mean Grain Size of γ (mm)	γ Phase: Cell Volume ($x10^{-1}$ nm^3)	γ Phase: Axial Ratio	γ Phase: Al Atom-Ratio[b] (at. %)
34Al	--	$\gamma+\alpha_2$[c]	10	0.1	0.6519	1.017	49.6
36Al	--	$\gamma+\alpha_2$	1	0.3	0.6523	1.019	49.9
38Al	--	γ	Zero	0.6	0.6526	0.021	52.1
40Al	--	γ	Zero	1.0	0.6533	1.024	54.2
34Al		$\gamma+\alpha_2$	I	D	I	D	SI
36Al	Zr	$\gamma+\alpha_2$	I	D	I	D	SI
38Al		$\gamma+\alpha_2$	SI	SD	I	D	SI
34Al	Nb	$\gamma+\alpha_2$	I	D	SI	SD	SI
38Al		$\gamma+\alpha_2$	SI	SD	SI	SD	SI
34Al		$\gamma+\alpha_2$[d]	D	D	D	C	C
36Al	V	$\gamma+\alpha_2$[d]	SD	SD	D	C	C
38Al		γ	Zero	C	D	C	C
34Al		$\gamma+\alpha_2$[d,e]	D	D	D	D	D
36Al	Mn	$\gamma+\alpha_2$[d,e,f]	SD	·SD	D	D	SD
38Al		γ[g]	Zero	C	D	D	C

[a]I, D, C, and S represent changes caused by adding the third elements.
I = Increase; D = Decrease; C = Constant; S = Slight.

[b]Normalized by total number of Ti and Al atoms in the γ phase.

[c]Annealing twin decrease with increasing Al content in Ti-Al binary alloys.

[d]Annealing twin increase with increasing third element.

[e]The ternary alloys containing more than 5 at. % Mn are three phases; $\alpha_2+\gamma+\zeta$. ζ is $Ti_3Al_3Mn_2$, which is ordered hexagonal with a=0.4997, c=0.8908 nm.

[f]The alloy containing 2.5 at. % Mn is the γ-single phase.

[g]The alloy containing above 5 at. % Mn is the $\gamma+\zeta$ two phases.

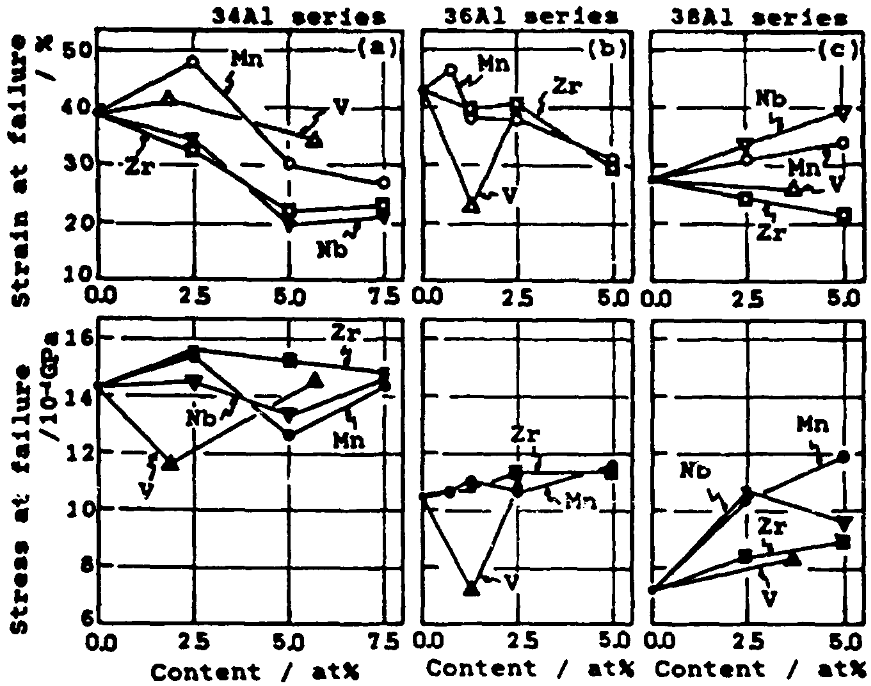

Figure 4. Effect of alloying elements on compression properties of Ti-Al alloys (from Ref 14).

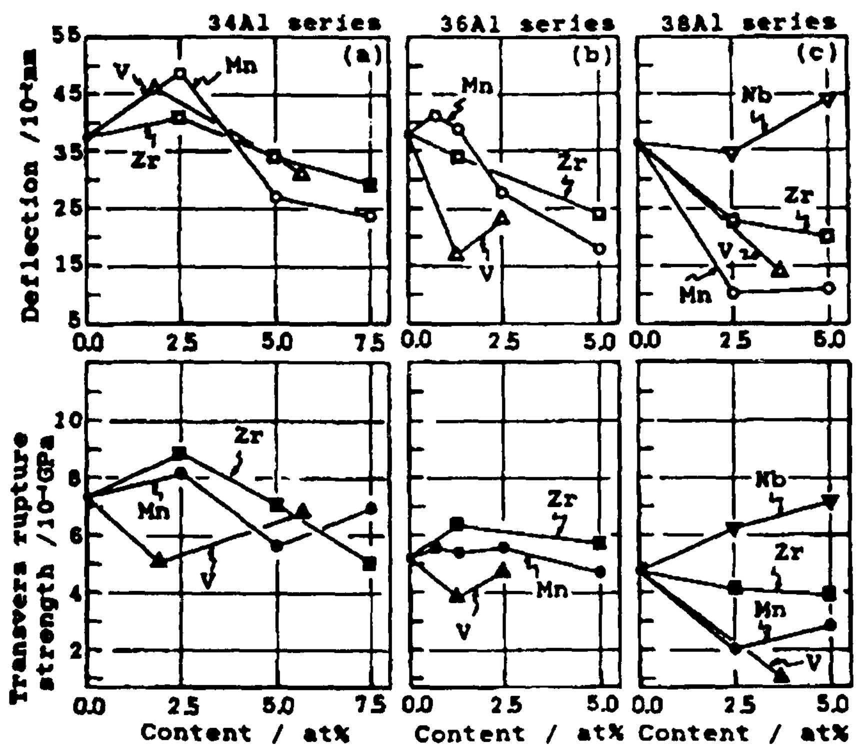

Figure 5. Effect of alloying elements on bending properties of Ti-Al alloys (from Ref 14).

- Production of Advanced Powders by Centrifugal Atomization (K. Harada)

- Production of Rapidly Solidified Alloy Powders by Super High Pressure Liquid Atomization (T. Takeda)

- Gas Adsorption-Desorption Characteristics of Ultra-Fine Powders and Their Bonded Porous Structures (Y. Sakka)

Ikeno et al. (Ref 16) have investigated the relationship between sintering conditions and substructures of dispersion strengthened Ni-Mo-TiC alloys. Mixtures of Ni, Mo, Mo_2C, and TiC powders about 3 μm in diameter were mixed and reduced to 0.3 μm using n-hexane and a ball mill. The milled powders were dried and hot pressed by using carbon dies in a vacuum cell (10^{-3} Pa, 1,500 K, 10 MPa piston pressure). The apparent densities of samples were compared using different sintering procedures. With the use of a liquid sintering agent densities were increased from a range of 94-98 percent to 99.7-100 percent. Furthermore, the hardnesses of the samples fabricated by using the liquid were 5 to 30 percent higher. In the case of the samples prepared without using the liquid sintering agent, homogeneous distribution of the component particles, 0.3 μm in diameter, had been achieved. Incoherent interfaces with no dislocations at the boundaries were evident. The substructure of the specimens prepared by using the liquid phase consisted of microcrystals, 2 μm in diameter, but the TiC particles were 0.3 μm in diameter. Dislocations were observed at the interfaces of the homogeneously distributed TiC particles.

MATERIALS RELIABILITY

The goal of the materials reliability thrust is to use materials with confidence under any conditions. Fracture and deformation mechanisms are being examined under various conditions and new techniques to evaluate materials are being developed. This thrust includes the **Failure Physics Division**, the **Environmental Performance Division**, and the **Materials Life Prediction Research Group**.

Some of the research themes being pursued in the **Failure Physics Division** are:

- Nondestructive Evaluation of Materials (T. Saito)

- Effect of Slip Modes on Fatigue Damage Initiation in TiAl Intermetallic Compounds (K. Yamaguchi)

- Damage Measurement and Analysis (N. Shinya)

- Control of High Temperature Damage and Life Extension Techniques (N. Shinya)

Yagi et al. (Ref 17) have investigated the initiation and growth of surface cracks and inte... acks including cavities formed in 316 stainless steel under combined creep-fatigue loading at temperatures of 550, 650, and 750 °C. At 550 °C the fracture was caused by the formation, growth, and linkage of wedge-type intergranular cracks that formed due to hardening of the matrix resulting from strain aging induced by both creep and fatigue. At 650 °C fracture was caused by the transgranular growth of surface cracks under fatigue loading or the linkage of internal cracks under creep loading. No interaction between initiation and growth of surface cracks and growth of internal cracks was observed. The fracture at 750 °C resulted from the intergranular growth of surface cracks accelerated by the formation of internal cavities at the surface crack tip due to the creep loading.

The research themes included in the **Environmental Division** include the following:

- Characteristics of Exposed Surfaces During Fatigue (S. Matsuoka)
- Evaluation Methods for Threshold Stress of Structural Steels in Stress Corrosion (T. Aoki)
- Corrosion Evaluation of Metals (T. Fukushima)
- Evaluation of the Effect of Surface Films on Environment-Induced Fatigue Crack Initiation (K. Kanagawa)
- Fatigue Crack Propagation Under Random Loadings in Corrosive Environments (A. Ota)

Masuda and Nishijima (Ref 18) have studied the effects of both electrochemical and mechanical factors on fatigue crack propagation in SCM 435 steel (Fe-0.35C-0.28Si-0.78Mn-1.09Cr-0.16Mo wt. %) in 3 percent NaCl aqueous solution. The crack growth rate was concluded to be accelerated by anodic dissolution at potentials of -600 mV and low ΔK (stress intensity factor) values. From these results they concluded that crack growth behavior can be predicted provided adequate data are available in regards to the electrochemical and mechanical factors involved in the corrosion-fatigue process.

Takei and his coworkers are involved with numerous projects concerned with high temperature oxidation, hot corrosion, and coating development and evaluation. A program, performed in conjunction with burner rig operators throughout Europe, the United States, and Japan, is directed at the standardization of burner rig testing. This group is also heavily involved in coatings development not only for corrosion resistance but also wear resistance and other properties such as gas adsorption characteristics. The formation of TiC coatings on steels has received much emphasis. The relationship between coating conditions and properties of TiC layers formed by ion plating has been investigated extensively (Ref 19). It has been shown that coating rates, compositions, lattice parameters, hardnesses, and adherence depend on experimental conditions in different ways. Consequently the coating conditions must be selected with extreme care and will depend upon the particular characteristics of the coating of greatest importance for the intended application. Techniques are also being studied where particles of TiC can be formed in coatings such as Ni, Fe, Cu, or Al on various alloy substrates. In this latter approach, vapors of nickel (or iron, cobalt, copper, etc.) and Ti are established over the surface of the alloy to be coated and a gas such as CH_4 is added. By appropriate control of the experimental conditions a coating of nickel containing a very fine dispersion of TiC can be formed.

The **Materials Life Prediction Research Group** has the difficult task of attempting to predict the useful lives of materials in different applications. Some of the research themes are as follows:

- NRIM Fatigue Data Sheets (S. Nishijima)
- Development of Knowledge Based Systems for Materials Life Prediction (T. Takeuchi)
- Assessment of Creep Strength in Welded Joints (Y. Monma)
- Mechanisms of Intergranular Attack of Nickel-Base Alloys (T. Ishihara)
- Fatigue Life Prediction in Notched Materials (M. Nihei)

NRIM has been systematically conducting testing programs to characterize the creep and fatigue properties of engineering materials for structural use. This type of information is published as the series of NRIM Creep and Fatigue data sheets. As illustrated in Figure 6 the factual database as well as a knowledge base also generated at NRIM and by using the literature are to be used to establish an integrated materials life prediction system that will be implemented on a distributed computer system.

TSUKUBA LABORATORIES

The Tsukuba Laboratories consist of the **Mechanical Properties Division**, the **Surface and Interface** Division, the **Superconducting Materials Research Group**, and the **Nuclear Reactor Materials Research Group**.

The **Mechanical Properties Division** has research projects concerned with the mechanisms of strengthening and toughening. Some of these projects are:

- Compatibility of Ferritic Steels and Liquid Metals (T. Suzuki)
- Fatigue Behavior of Metallic Carbides and Oxides (S. Horibe)
- Improvement of Fretting Fatigue Properties (M. Sumita)
- Mechanisms for Strengthening, Toughening, and Improving Mechanical Properties of Titanium Alloys (T. Kainuma)

Research is being performed on titanium alloys to advance the understanding of strengthening and toughening mechanisms and to attempt to improve performances by using new processing techniques. The influence of grain refinement and precipitation hardening on the strengths and toughnesses of β type titanium alloys is being studied by controlling the morphologies of dispersed oxide particles and aged α phases through thermomechanical processing. The fabrication of alloys, which are difficult to prepare by using conventional melting and casting techniques, is also being investigated by using powder metallurgy in conjunction with powder preparation via rapid solidification processes. Some results obtained with Ti-6Al-4V are presented in Figure 7. A new processing technique using elemental powders resulted in a finer grain size product than the conventional processing procedures. The results obtained from fatigue tests (Figure 7) show that the new processing sequence has resulted in alloys with improved fatigue characteristics at stress levels below about 75 kg/mm^2.

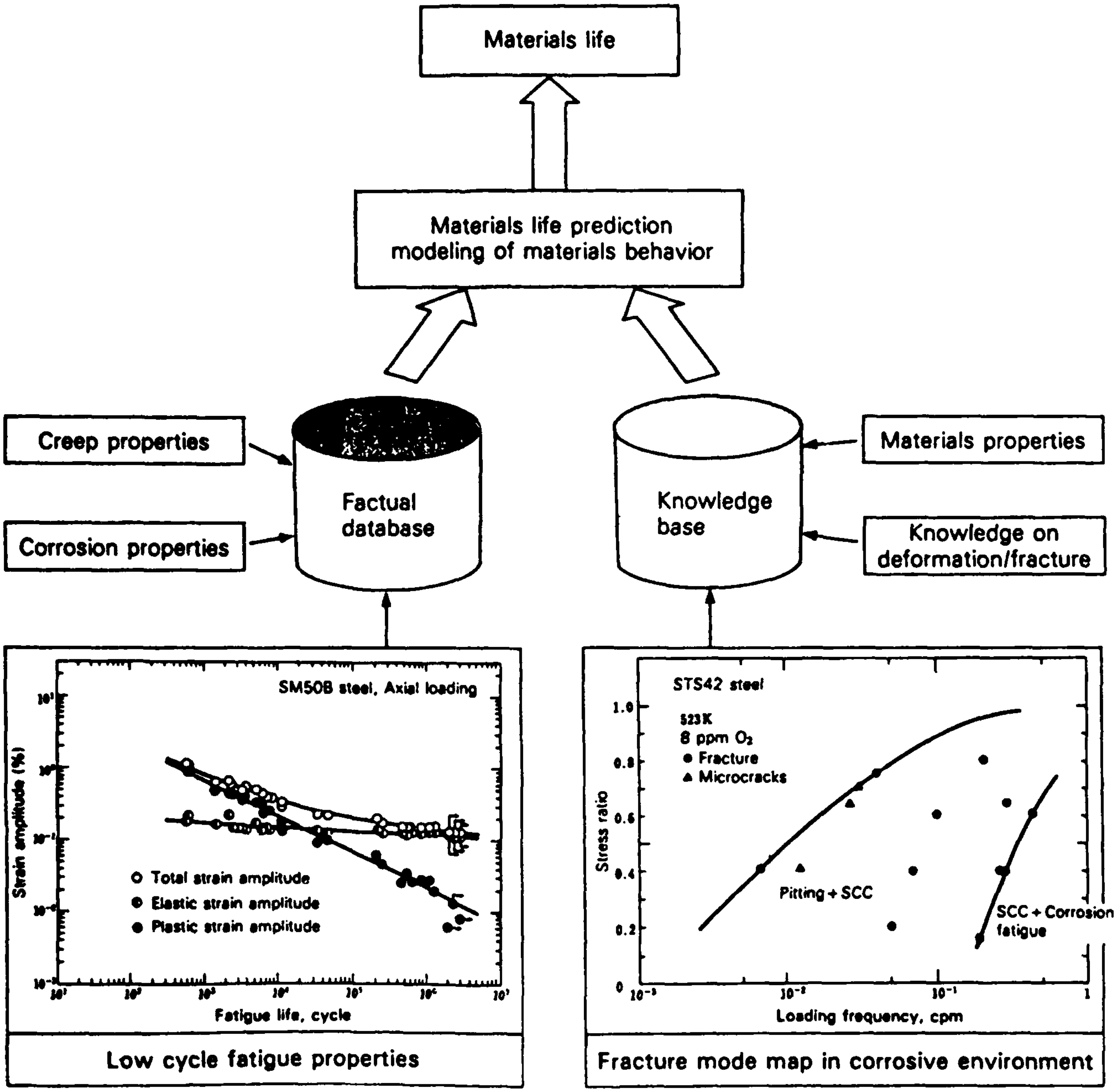

Figure 6. Schematic of NRIM planned materials life prediction system (reprinted with permission of the National Research Institute for Metals).

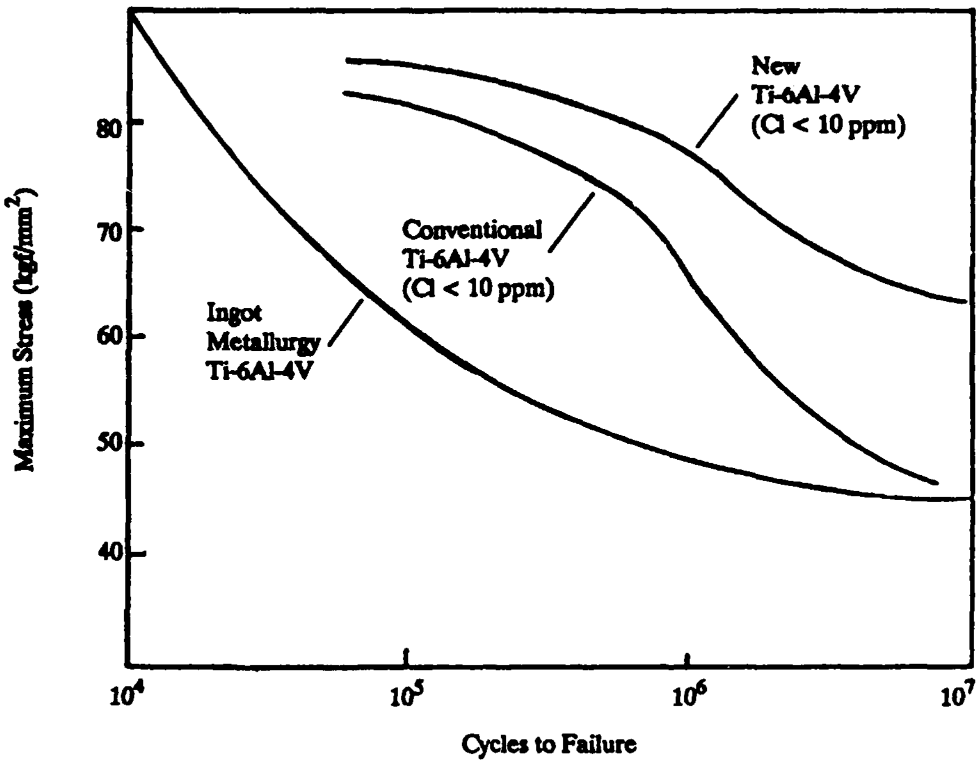

Figure 7. Comparison of fatigue properties of Ti-6Al-4V fabricated via casting, conventional powder metallurgy using elemental powders, and a new powder metallurgy procedure using elemental powders.

The structures and mechanical properties of a number of silicides and aluminides are being characterized. These studies have emphasized the preparation of single crystals using the floating zone method. This approach of using single crystals has resulted in some improved mechanical properties compared to the polycrystalline counterparts. Such materials can be susceptible to degradation via pesting (concomitant oxidation and cracking that produces fine, powdered product) and the single-crystal modifications may be more resistant to this form of degradation.

Some ceramics are also being studied such as SiC and Si_3N_4. Investigations to elucidate the mechanisms of deformation and fracture of such materials at high temperature with particular emphasis on fatigue are being performed.

The effect of liquid metals such as sodium and mercury on the degradation of the mechanical properties of stainless steels is being investigated. Specimens of stainless steel are exposed to environments containing these liquid metals and vapors at controlled temperatures and flow velocities. After exposure for various times specimens are subjected to a number of mechanical tests. This research is involved with mechanisms by which the mechanical properties become deteriorated by the liquid metals and approaches to obtain improved performances.

Studies are being performed to develop improved models for the fracture of alloys under the influence of frictional surface forces and cyclic loads in corrosive environments. These investigations are concerned with titanium alloys and stainless steels whereby surface properties are modified using methods such as ion implantation.

The **Surface and Interface Division** hopes to eventually tailor materials to have certain properties. To manipulate atomic and electronic structures the following approaches are being used: (1) exploitation of physical and chemical properties peculiar to surfaces and interfaces (e.g., surface segregation of carbides and borides on an alloy surface); and (2) synthesis of new materials (e.g., thin and multilayered metallic films and use of ion implantation technology). Some current research themes being pursued in the Surface and Interface Division are:

- Transition Phenomena of Magnetic Superconductors at Low Temperatures (M. Uehara)
- Diffusion Behavior of Structure Controlled Thin Films (K. Yoshihara)
- Microstructural Modification of Surfaces and Interfaces by Using Beam Techniques and the Related Property Changes (K. Saito)
- Development of Intermetallic Compounds for Advanced Luminescent Devices (N. Koguchi)

Nii and coworkers (Ref 20-22) have been investigating the surface precipitation of carbide and nitrides on a number of metals and alloys with emphasis on stainless steels. Carbide films can provide wear resistance and boron nitride is considered to be inert to the adsorption of gases and therefore can be a suitable coating for vacuum vessel walls. The experimental approach involves heating alloys in vacuum at elevated temperatures, where the alloys initially contain homogeneously distributed carbide or nitride precipitates. During the vacuum anneal surface precipitation of these internal precipitates can occur when such processes lower the total free energy. It has been observed that some properties, such as adherence, of surface precipitated layers can be better than those of the same layer formed via deposition from the gas phase. Surface precipitation is also being studied after ion implantation is used to develop concentration profiles of different elements near the surfaces of different alloys (Ref 21).

The **Superconductor Materials Research Group** at NRIM has been described in previous articles in the *Scientific Information Bulletin* (Ref 23-24). It is part of STA's Multi-Core Project (Ref 23). The Superconductor Materials Research Group is responsible for the High Field Properties Core and the Conductor Core of this project. Some current research themes are:

- New Fabrication Techniques for High T_c Superconductors (H. Maeda)
- Vapor Deposition Processes for High T_c Superconductors (Y. Tanaka)
- High T_c Superconductors Produced by Chemical Reactions (H. Wada)
- Wire Fabrication Processes for High T_c Superconductors by Solid State Liquid Phase Reactions (K. Togano)

- Development of Extremely High Field Magnets (H. Maeda)

Some of the other divisions and research groups at NRIM are also responsible for some core projects as indicated in the following:

- Theory Core
  - Electronic structure and superconducting mechanism in high temperature superconductors (T. Oguchi) (Materials Physics Division)
- Database Core
  - Database development for new superconducting materials research (Y. Asada) (Materials Design Division)
  - Investigation of trends toward practical application of superconductors (K. Hoshimoto) (Materials Design Division)
- Purification Core
  - Purification of active metals for the preparation of superconducting metals (R. Hasegawa) (Chemical Processing Division)
  - Preparation of ultra-fine powder for superconductive materials (M. Ozawa) (Advanced Powder Processing Research Group)
  - Powder properties of superconductive materials for high pressure forming (Y. Kaieda) (Advanced Powder Processing Research Group)
- Thin Film Core
  - Fabrication of high T_c superconductor films by alternate, reactive evaporation method (K. Nakamura) (Surface and Interface Division)

As discussed in a previous *Bulletin* article (Ref 24), the Superconducting Materials Research Group at NRIM is well known for developing superconducting magnet wires of conventional superconductors and efforts are now being directed to developing wires of high T_c superconductors. This group is also responsible for the discovery by Maeda et al. of the bulk Bi-Sr-Ca-Cu-O superconductor (Ref 25). Recently NRIM and Asahi Glass Co. Ltd. announced that they had succeeded in preparing a flexible Bi-based T_c superconductive tape that can be wound into a coil. This flexible tape was produced by mixing a Bi-based (Bi, Pb, Cu, Sr, Ca, O) superconductor powder and an organic binder with other additives in trichloroethylene to obtain a viscous paste. This paste was spread upon a 12.5-cm-wide polyester film and cut into 3-cm-wide segments. These segments were heated for 1 hour to remove volatile impurities, placed between two stainless steel plates, and rolled to a thickness of $30\,\mu$m with mild heating. These tapes exhibited zero resistance at a T_c of 107 K with a current density of over 2,000 A/cm^2. These characteristics did not change substantially when the tape was wound at a diameter of 3 cm. Such tapes have potential value for applications of high T_c superconductors in high performance magnets, power storage coils, and wires.

The **Nuclear Reactor Materials Research Group** is concerned with materials for prospective energy sources of the next generation, such as fusion, fast breeder reactors, and high temperature gas-cooled reactors. Cyclotron irradiation with light ions is being used to simulate the fast neutron irradiation damage typical of these advanced reactors. Procedures to prevent radiation-induced materials deterioration, such as irradiation creep, swelling, and helium embrittlement, are being investigated. To develop a basic understanding in regards to radiation damage on the atomic scale, innovative techniques are being investigated by which the microstructural details of materials during ion and electron bombardment can be evaluated. For example, a facility is currently being established whereby dynamic, in-situ analyses and evaluations can be performed of materials being irradiated. Some current research themes being pursued in this group are:

- Development of Fusion Reactor First Wall Materials
    - High Heat Flux Materials (H. Shinno)
    - Chemical Reactions of Materials with Activated Hydrogen Isotopes (M. Kitajima)
    - Radiation Damage Resistance of Microstructure Controlled Materials (N. Kishimoto)
- Advanced Intermetallic Compounds for Nuclear Reactors (M. Nakamura)
- Characterization of Advanced Superconductors for Fusion Reactor Magnets (H. Wada)
- Analysis of Damage/Endurance Relationships in Structural Materials for High Temperature Gas-Cooled Reactors (T. Tanabe)

An example of some of the research being performed in the Nuclear Reactor Materials Research Group is that by Kimoto and Shiraishi (Ref 26,27). The dose rates in ion and electron irradiations are generally 2 to 4 orders of magnitude higher than in a reactor. It is necessary to examine the influence of dose rate on void swelling and precipitation behavior during irradiation. Type 316 stainless steel and a Japanese alloy (PCA) were exposed to 200 keV proton irradiation at two different dose rates and void swelling and precipitation behavior were compared. In the case of 316 void swelling was large at both dose rates. For the PCA alloy, however, void swelling was much lower for the low dose rate irradiation compared to the high dose rate. It was also determined that during aging the precipitation of TiC in type 316 was not significantly affected by proton irradiation, but in PCA much more precipitation occurred for the low dose rate irradiation. It was concluded that the smaller amount of swelling of PCA at the lower dose rates of irradiation was due to the formation of fine TiC precipitates that supplied recombination centers for vacancies and interstitials. From these results it was proposed that void swelling will be suppressed much more effectively by fine TiC precipitates in the neutron irradiation for which dose rates are extremely low compared to ion irradiation.

CONCLUSIONS

The quality and the levels of sophistication of the research being performed at NRIM are comparable to that being performed in many laboratories in the United States. This research is still very applied and probably will remain that way for 10 years even if the emphasis on more fundamental approaches is maintained. The research concerned with modification of surfaces using ion beams, deposition of thin coatings of carbides and nitrides via chemical vapor deposition, and superconductivity is at the cutting edge of these technologies. The materials processing and materials reliability efforts are investigating with very good advantage techniques, processes, and procedures that have been developed as much as 10 years ago.

While there is no question that the Japanese intend to emphasize basic research, the in-depth, sophisticated investigations at present are in those areas where markets exist for their products. An example is the area of high temperature materials used in gas turbines. In the past this market has not been available to the Japanese except for industrial gas turbines, whose technology is not as advanced as aircraft or marine gas turbines. Consequently, most of the Japanese research and development on such materials is state-of-the-art in nature as opposed to being at the very cutting edge of innovating new technology.

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CURRENT STATUS OF THE CARBON FIBER INDUSTRY IN JAPAN

Sin-Shong Lin

The information contained in this report was gathered during a 7-week trip to the Far East as part of the expanded mission of the Army Material Technology Laboratory (MTL) to survey recent developments and advances in carbon fibers. Carbon fibers are known to play a significant role in fiber-reinforced materials for lightweight structures and other high-performance applications. Increasing applications are expected in many types of aerospace and commercial components in the near future. In this article, a brief description of the carbon fiber manufacturing process is given, followed by recent efforts of the Japanese carbon fiber industries, such as current status, progress, research highlights, and process development. Some relevant technical problems and possible improvements of the fiber process are discussed.

INTRODUCTION

There is a wide variety of available carbon fibers. Generally, commercially available carbon fibers (CF) in Japan can be grouped into polyacrylonitrile (PAN) and pitch-based fibers based on the precursor materials, either polyacrylonitrile or petroleum pitch/coal tar. The commercial PAN-based fibers usually have medium to high tensile strengths, while the pitch-based fibers tend to have high tensile modulus. This distinction is becoming less valid due to the availability of the medium-high modulus grade PAN fibers. The pitch-based CF currently available are further divided into general-purpose (GP) grade, usually short fibers of lower mechanical strength, and high-performance (HPCF) grade, fibers with excellent mechanical properties comparable to the high-quality PAN fibers. Furthermore, according to the mechanical strength, the fibers are grouped into high tensile strength (HT), high modulus (HM), ultra high modulus (UHM), and high elongation. The commercial applications of these fibers are quite different based on their physical and mechanical properties. The PAN-based fibers are used mainly in lightweight structural components such as aircraft secondary frames and leisure products. The GP fibers are used widely in high-temperature insulating materials, reinforcements for engineering plastics, carbon materials and concrete, and as an alternative to asbestos. But for HPCF, the major applications are in the fabrication of advanced composite materials for aerospace equipment based on the material strength, rigidity, electric, and other properties. Also some applications are in the carbon/carbon (C/C) composite materials for rocket components based on unique high-temperature properties.

The worldwide consumption (Ref 1-3) of all carbon fibers, including high-performance and general-purpose PAN- and pitch-based fibers, exceeded 7,500 tons in 1987 (Ref 2), of which more than 85 percent are PAN-based fibers. The demand is expected to increase due to the development of many new applications, especially in the field of fiber-reinforced concretes, fiber-reinforced plastics, and other structural reinforcement utilizations. Of worldwide demand, Japan produces two-thirds of the world production and consumes only one-third or less. Accordingly, in Japan much attention is focused on the progress and development (Ref 4,5) as well as the production of carbon fibers. The fabrication technology for PAN fiber was originally developed in Japan in 1958 (Ref 6) and has been improving steadily since then. Several large Japanese manufacturing corporations, such as Toray, Toho, Mitsubishi Rayon, and Kureha, are actively searching for alternative process improvements for higher strength fibers as well as expansion of material applications. The manufacturing process and technology of medium-grade PAN fibers are well established at this time as are production methods. The GP pitch-based fibers, which were first produced from isotropic pitches in 1970 (Ref 7,8), are commercially available for low-cost reinforcement of building materials. However, the HPCF pitch-based fibers produced from anisotropic or mesophase pitches are still in the developmental stage, although a few of the products are currently on the market.

Pitch-based carbon fiber is emerging as a material competitive with the PAN-based fiber in both performance and cost. The possibility of encroachment of the existing PAN fibers market by the new pitch-based fiber is the subject of many arguments and discussions (Ref 1). Regardless of the uncertainties in the future economic outlook, pitch-based fibers have several advantages that should not be ignored:

(1) The fiber is a higher added value product made from the readily available low cost materials, petroleum pitch and coal tar.

(2) It has excellent physical properties comparable to the PAN fibers.

(3) The manufacturing processes are reported to be simpler than the processes for PAN fibers.

(4) The future economic outlook is very optimistic based on market projections.

The two largest producers of PAN fibers, Toray and Toho Rayon, are located in Japan. The combined production capacity of both companies exceeds 3,000 tons per year, which is about 40 percent of the worldwide production (Ref 2). The total production of PAN fibers around the world is about 85 percent, and the remaining 15 percent or less is mostly general-purpose pitch-based fibers produced by Kureha Co., Mitsubishi Chemical Co., and Osaka Gas Co. Some high-grade pitch-based fibers are available from Mitsubishi Chemical, Kashima Oil, and Osaka Gas. In Japan there are over 25 companies actively engaged in the development of pitch-based carbon fibers, and their activities and progress have shown varying degrees of success. Although most of the companies are not yet in the production stage, their research efforts are expected to produce a breakthrough in the low-cost processing technology for high-performance fibers.

OVERVIEW OF MANUFACTURING PROCESSES

The basic process for manufacturing CF (Ref 9-11) consists of a series of steps involving: (1) precursor preparation,

(2) spinning, (3) thermosetting, (4) carbonization, (5) graphitization, and two additional processes of (6) surface treatment and (7) epoxy sizing (Ref 12). However, the procedures involved in the processing are proprietary and are not released by the manufacturers.

In the PAN CF process, a special polyacrylonitrile copolymer fiber is stretched to align the polymer chains parallel to the fiber axis, and these linear backbones are converted into ribbons of continuous hexagonal carbon rings by oxidation (stabilization). This type of fiber has a sufficiently high glass transition temperature so that part of the orientation is retained after a carbonization cycle to 1,000 °C. Most elements other than carbon are removed during the combustion. The evolution of gases such as CH_4, CO_2, H_2O, NO, and a trace of HCN is observed. The orientation of the ribbons is further improved by heating to higher temperatures (carbonization or graphitization temperatures), which increase the modulus of the fiber. The conversion yield is less than 50 percent.

For the pitch-based CF, the precursor is a purified fraction of coal tar or petroleum pitch containing a large amount of liquid crystals or mesophases. In the process of melt spinning, the sheet-like aromatic hydrocarbons are easily oriented parallel to the fiber direction. The fibers are made infusible by oxidation (stabilization) and then carbonized, followed by graphitization. The crystallites in the pitch fiber are usually larger and better aligned than those in the PAN fiber and are oriented like strips of ribbon running along the fiber length. Consequently, the mesophase pitch fiber yields a high modulus. The conversion yield of pitch fiber is more than 90 percent.

PRECURSOR MATERIALS

PAN-Based Carbon Fibers

Specially processed polymer fiber is currently used for industrial production. The constituents of the fiber are somewhat different from the fibers used in textile fabrics in that the coloring, sizing, lustering, antistatic, and brightening compounds are absent. Additional chemicals are added to the polymer fiber to facilitate the stabilization and carbonization processes at the later stages. The starting PAN precursor contains at least 90 percent acrylonitrile units copolymerized with chemicals such as methylacrylate, methylmethacrylate, vinyl chloride, or vinyl acetate to achieve different molecular configurations. The additives can be divided into categories based on the objectives. Organic or inorganic phosphorous or halogen containing compounds are coated mainly to prevent excessive oxidation during the stabilization process. Aromatic compounds to aid fiber crystallinity and preferred orientation during the manufacturing process are also used. Precursor fibers without excessive macrovoids and with minimum micropores are highly preferable. Since the precursor composition is a prime factor in the final mechanical strength of the synthesized CF, manufacturers tend to follow their own proprietary formulations.

The preferred alignment and orientation of the polymer molecules along the fiber direction are a prime concern in the production of the precursor fiber. To improve the alignment in the polymer structure, the as-spun PAN fibers are frequently stretched by 100 to 500 percent at about 100 °C. Also during the carbonization process, the tensile stretching in either a single, gradual stage or in multiple stages is a necessary production procedure. Copolymerization with vinyl chloride or with other polymers to promote complete carbonization and preferred orientation is the subject of ongoing research efforts. The average molecular weight as well as the molecular weight distribution are also considered in the final formation of the PAN polymer filaments. The control of variation in the average molecular weight of copolymers can improve the mechanical strength or the physical characteristics of the resulting CF. Since modification of the precursor polymer chemistry greatly affects the processing parameters, research is focused on the modifications within the limit of the current production technology.

Pitch-Based Carbon Fibers

Pitch is a mixture of condensed aromatic hydrocarbon with or without alkyl branches, and conventional pitches show no optical anisotropy. The molecular weight of an individual pitch unit varies widely and may be in the range of 300 to 4,000. Thus pitch usually has a molecular weight distribution depending on the source and the processing condition. Accordingly, the pitch constituents can be grouped into benzene, quinoline, and pyridine soluble/insoluble components (Ref 13).

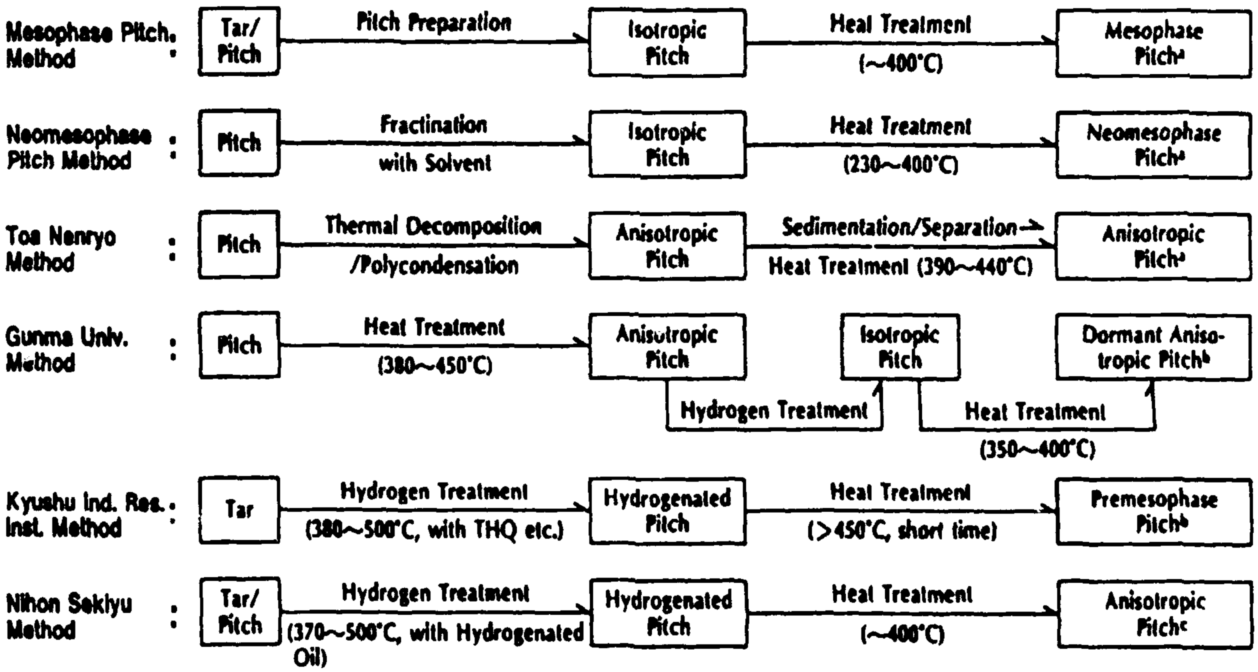
For the production of GPCF the precursor is isotropic pitch, which contains a wide variety and range of molecular structures and is usually less pure. However, the HPCF precursor is anisotropic pitch so that fibers with highly oriented crystallites can be obtained during the spinning process.

When feed pitch is heated to remove low molecular weight volatile components, larger polynuclear aromatic compounds are formed. Around 400 °C, the melt starts to separate into two phases. One phase appears as spherule and grows larger with increasing temperature. This phase is optically anisotropic and is the so-called mesophase. The second phase is the remaining isotropic melt. This anisotropic mesophase consists of large planar polynuclear aromatic molecules aligned together by weak Van der Waals forces, and it has a higher density than the surrounding isotropic phase. Gradually the anisotropic phase will aggregate by gravity sedimentation. If these two phases are separated, the anisotropic mesophase can be used as a starting raw material for HPCF.

After de-ashing, if necessary, the isotropic phase can be spun into filaments (GPCF) of low tensile strength and modulus. A slightly higher mechanical strength of the fiber can be obtained if a better isotropic pitch, either of a larger average molecular weight or a high purity precursor, is used.

The pitch obtained after direct heating is hard to process into fiber because: (1) the viscosity is too high at the softening temperature for easy spinning; (2) the condensation to larger molecules (infusible matter) and gas evolution continue at this temperature; and (3) two phases, anisotropic mesophase and isotropic matrix, exist together, making it difficult to process into fibers. The process used by Union Carbide Co. (AMOCO Co. now) is a modified method of direct heating. An additional agitation mechanism is incorporated into the spinning process to homogenize the two-phase pitch (Ref 13).

There are several methods (Figure 1) to separate or to generate anisotropic mesophase from the raw materials, petroleum pitch or coal tar. The methods currently in use are hydrogen treatment with tetrahydroquinoline (THQ) (Kyushu Ind. Res.) (Ref 14) or with hydrogenated anthracene oil and catalyst (Nippon Petroleum) (Ref 15), thermal decomposition followed by gravity sedimentation (Toa Nenryo) (Ref 16), and the combination of heat treatment and solvent fractionation or hydrogenation (Ref 15). The basic principle involved in the above processes is to obtain a narrow molecular weight distribution of feed pitch in order to improve the crystalline size and the crystal orientation of the spun fiber. Words such as pre-, neo-, and dormant mesophases are often used to describe the final pitch compositions after the treatments as shown in Figure 1. The Kyushu method yielded a feeding pitch (premesophase) that was isotropic but became anisotropic after spinning. The spinnability or the softening point of pitch must be considered in the choice of the feed pitch composition. The best choice of pitch composition (Ref 17) is: (1) melting point between 240 and 300 °C, (2) 80 to 95 wt. % of benzene insoluble and 10 to 40 wt. % of quinoline insoluble, and (3) an anisotropic portion of 70 to 90 percent.



a: Optically anisotropic
b: Optically isotropic
c: Optically anisotropic but low QI

Figure 1. Typical preparation methods for precursor pitch (from Ref 15).

The current trend of the investigations is to find the best pitch composition that will provide easy spinnability and incorporate high mechanical strength into the resulting spun fibers. Thus, control of the spinning temperature and the precursor composition become very critical. From research efforts to improve the feed pitch composition, the present methods of attempting to narrow down the molecular weight distribution width of precursor pitch alone are not sufficient to obtain the optimum mechanical strength of CF. In order to manipulate fiber microstructure and to promote crystallite orientations, it seems necessary to create an entirely different composition of the feed pitch, such as two-pitch components (either anisotropic or isotropic) with varying softening points and molecular weight distributions. Perhaps an admixture of a second organic compound to promote perfect crystallization and preferred orientation for co-carbonization might improve the characteristics of the resulting spun fibers. Blendings of anthracene para-xylene-glycol (PXG), polyvinyl chloride (PVC) pitch, condensed polynuclear aromatic compounds (COPNA), $AlCl_3$ catalyst, and two-phase pitch have been experimentally tested (Ref 18-21). The roles of the additives are to: (1) act as a solvent to decrease the pitch viscosity, (2) react with feed pitch to modify condensation and aggregation processes by new reaction intermediates, and (3) promote sol polymerization reaction. If the microstructure and the surface morphology of the fibers could be controlled and manipulated, crack propagation, which is often initiated from surface flaws, would be retarded and reflected. Hopefully, the highest CF strength would be obtained.

SPINNING AND MICROSTRUCTURE CONTROL

In melt spinning pitch-based CF, the spinnability is the most important factor governing the filament drawing process. Since the softening temperature of the precursor pitch is 300 °C or more, the process has to be performed at a temperature 20 to 30 degrees higher. Thus, the proper viscosity is absolutely required for easy spinning. Spinning at higher temperatures accelerates degradation and aggregation of pitch molecules, producing infusible residues. Spinning at lower temperature and at a high viscosity produces discontinuous filaments.

It has been shown (Ref 17) that spinning at temperatures below or near the transition temperature of viscosity (T_s) tends to yield fiber with a radial type cross section (Figure 2). At a spinning temperature 50 °C or more above the transition temperature, a fiber cross section with an onion-type arrangement (Figure 3b) will be produced. In the intermediate temperature range, random or mosaic cross sections or mixtures of these patterns are formed (Figures 3a and 3c). The two pitches shown in the figure are hydrogenated in the autoclave either by THQ and hydrotreated anthracene oil (HAO) or by hydrogen gas in the presences of quinoline/anthracene solvents and catalysts (iron oxide, red mud, Co-Mo-alumina, or Ni-Mo-alumina) followed by heat treatment above 450 °C at a reduced pressure or inert gas bubbling. The viscosity transition temperature depends on the compositions as well as the sources of feed pitches.

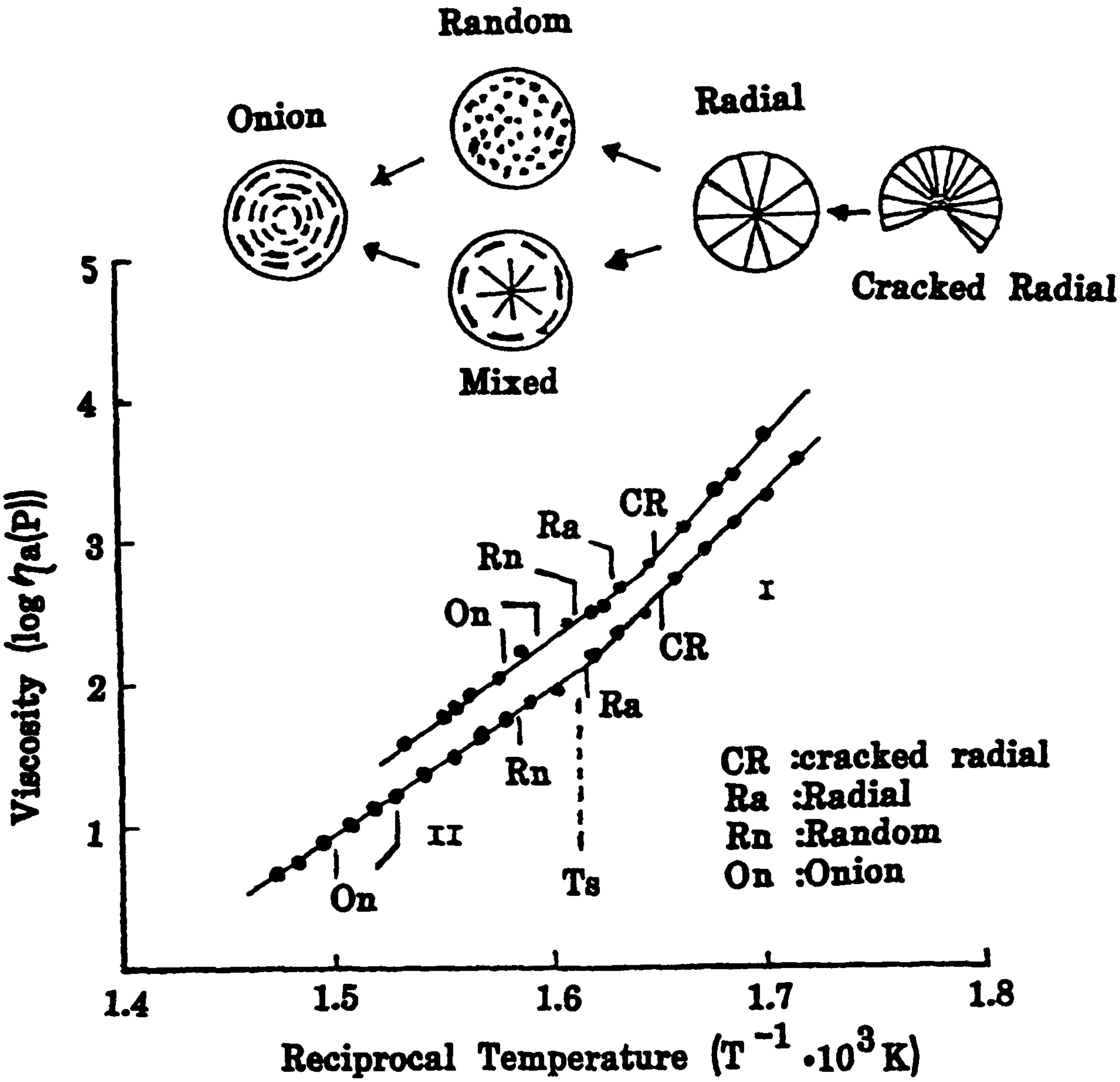


Figure 2. Variation of pitch-based fiber cross sections with softening temperature (from Ref 14).

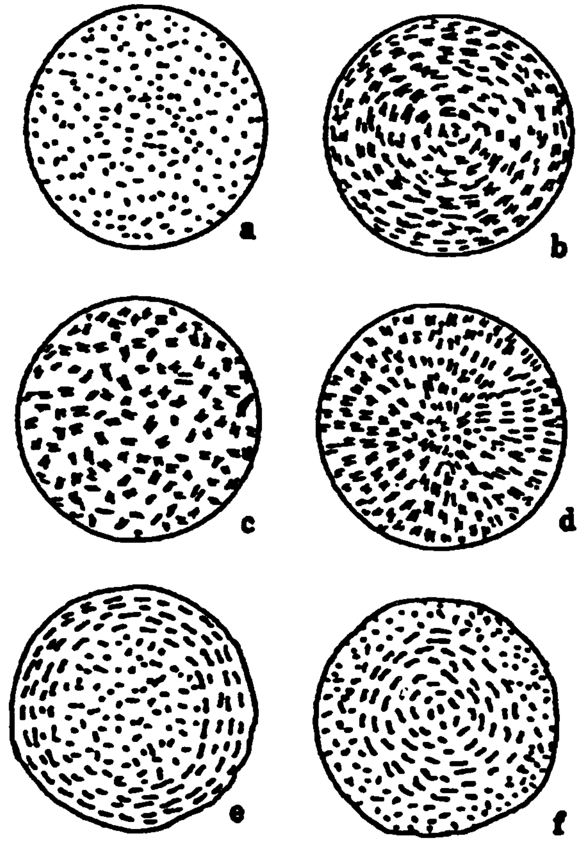


Figure 3. Microstructures of pitch-based carbon fiber cross section (after Ref 15).

The formation of the radial-type cross section (Figure 3d) in the fiber is not preferable due to large thermal shrinkage cracks (Ref 22) that often occur after cooling normal to basal planes of graphite/carbon layers. This type of cross section is presumably produced from a laminar flow of the pitch through the spinneret. Several attempts have been made to change laminar flow to turbulent flow by approaches ranging from changing the shape design of the spinneret, the wettability of the spinneret surface materials, to the addition of a stirring mechanism. The most effective and the simplest shape of the spinneret is when the orifice has little or no thickness (a "knife edge" shape). Nevertheless, the microstructure of the fiber cross section can be controlled by spinning temperature, drawing rate, spinneret shape, spinneret orifice, and the composition of precursor pitch (Ref 17).

The onion-type cross section is very desirable because crack propagation can occur only along the circumference of the fiber layers according to M. Endo (Ref 23). Thus, the tensile strength of the fiber will be sustained and is less affected by the presence of numerous surface flaws, which are the initiation points of crack formations. This view, however, is not entirely accepted by other scientists. According to Yamada, even in the onion-type cross section, it is impossible to have a perfect cylindrical arrangement of crystallite planes to divert all crack propagations. Preferred orientation and perfect alignment of graphite crystallites in the fiber are believed to be more effective in improving fiber strength.

Design of the fiber cross section by varying the feed pitch composition was also considered. By using a pitch precursor containing two different phases (Ref 17), such as one isotropic low melting and another anisotropic high melting, or isotropic high melting and anisotropic low melting, it is possible to produce a fiber cross section with varying patterns of the desired microstructure. A cross section with the onion layers on the outer circumference (Figure 3e) and the random mosaic microstructure on the fiber core (Figure 3f) has been experimentally attempted. However, the tensile strength of this fiber with the onion outer shell structure (Figure 3f) is not extraordinarily different.

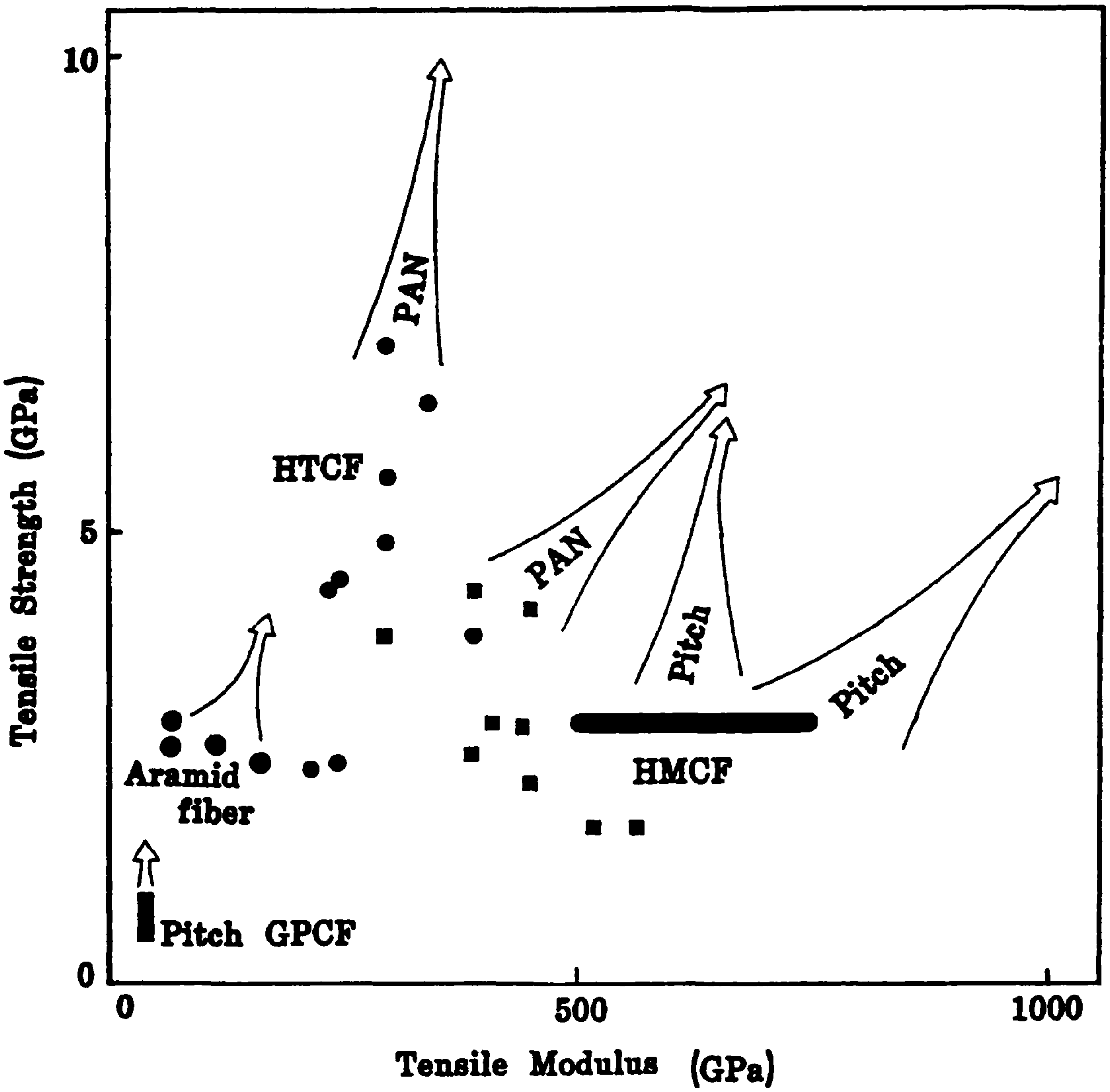
Several attempts to fabricate fibers with various types of cross sections have been made. By changing the shape of the spinneret and/or by using a stirring device, different cross-sectional patterns, such as elliptic, star, cross, and triangular, with diverse crystallite orientations have been obtained (Ref 4,17). The increase in the circumferences of the odd-shaped ones also increases the number of surface flaws. Consequently, no improvement in material tensile strength was observed. However, the elongated elliptic type of cross section was found to have the best alignment in which two rows of crystallite planes were oriented along the long axis. The tensile strength was also found to improve slightly.

Spinneret shapes other than circular, and with additional stirring devices, are hard to fabricate and may cause difficulties in the processing operation. Moreover, processing parameters such as temperature and draw ratio have to be modified. The alteration in the processing technology may not compensate for the small increment of mechanical strength derived from the noncircular, cross-sectional fibers.

Therefore, the major research efforts in the production of better quality carbon fibers have been in simplifying the preparation method of precursor pitches and finding a more economical processing technology. The immediate concern facing many producers at this time is the large variation of fiber properties from the pilot production line. The mechanical strength of a single filament changes unpredictably from batch to batch and also from segment to segment. This is the major reason that large-scale production of pitch-based fibers has not been fulfilled 10 years after the discovery of the anisotropic mesophase technology. The cause of this large variation in mechanical strength, which presumably is derived from a large fluctuation in random occurrences of surface flaws, is rather complicated. The problem might come from the inherent nature of the pitch precursor, unforeseen abnormalities in the spinneret and the spinning condition, external as well as internal surface contaminations, and/or stabilization and carbonization processes.

MECHANICAL PROPERTIES

The tensile strength and modulus of typical commercial CF are shown in Figure 4 (Ref 24). According to Figure 4, CF is grouped into three categories: PAN HPCF, p-GPCF, and p-HPCF. The PAN-based fibers are mainly located at the high strength side (3 to 7 GPa) with medium modulus (2 to 300 GPa), while pitch-based HPCF are situated at medium strength (3 GPa) with a wide range of modulus (4 to 800 GPa). It seems that PAN CF are better in tensile strength than pitch HPCF, and the reverse situation exists for tensile modulus. Currently PAN CF M40 made by Toray is commercially available. This fiber has a tensile strength of 4 GPa and a modulus of 400 GPa, which put it in the region bridging the two outstanding features of the PAN and pitch fibers. The fiber currently available with the best tensile stress is Toray T1000 (7 GPa). The highest modulus fiber is pitch CF at 800 GPa. If the current rate of improvement continues, high strengths of 10 GPa for PAN CF and 5 GPa for pitch CF will be attainable within 3 years. The probable directions of future developments for these fibers are indicated by the arrows in the figure.



Square:	Pitch-based CF
Circle:	PAN-based CF (small); Aramid fibers (large)
Arrow:	Future trends
CF:	Carbon fiber
HT:	High strength
HM:	High modulus
GP:	General purpose

Figure 4. Mechanical properties of carbon fibers and future trends (after Ref 24).

CF has many superior characteristics uncommon to other materials, such as specific strength, specific modulus, small thermal expansion, excellent fatigue resistance, good corrosion resistance, good damping characteristics, etc. However, one shortcoming other than combustibility is low fracture toughness. The toughness, which is the energy required to fracture material, is about one-tenth of Al alloys. Therefore, improvement in material toughness is urgently needed for the future applications.

To improve the fracture toughness of the CF-reinforced composites (CFRC), a few alternatives and modifications are currently available:

(1) Improving CF strength by designing new microstructures, or creating an admixture of aramide fibers to form a so-called hybrid composite.

(2) Enhancing the energy-absorbing mechanism of the composite resin by adding elastomer or thermoplastic polymer and designing a new composition of resin matrix.

(3) Varying the levels of interfacial adhesion to absorb excessive energy by delamination or fiber pull-out.

The alternative to the last method is to use elastomer as a sizing compound on the surface of CF. The energy-absorbing nature of the elastic interface could prevent fiber delamination and enhance the fracture toughness of the CF-reinforced composites.

PRESENT AND FUTURE APPLICATIONS

The applications of CF to structural components have increased steadily over the past several years. The fibers have been used in applications ranging from the advanced fiber-reinforced composites in the space shuttles and airplane secondary components to biomedical utilization in dental implants.

One of the more significant developments is the application of GPCF in low-cost construction material as a reinforcement (Ref 25 and 26). GPCF traditionally has been used for high-temperature insulating materials. However, in this new application GPCF is expanding into fiber-reinforced cements and concretes. Carbon fiber strengthens the weak tension and poor impact resistance of the conventional portland cement matrix. CF provides:

- Chemical inertness to acid and alkali
- High stability to biodegradation
- Higher tensile strength and modulus compared to concrete
- Good electric and thermal conductances
- High compatibility with cement and mortar

However, the effect of the fiber reinforcement is strongly dependent on fiber strength, formulation, content, and fabrication process, among others. The first and largest construction using CFRC is a 37-story building in Akasaka, Tokyo. Cost reduction is the largest motivation in the development of CFRC.

Another major expanding application of GPCF is in the field of CF-reinforced plastics. The unique properties of CF in electric conductance and magnetic shielding with moderate strength are the focal points of the application. The commercial use is expected to increase if the cost of GPCF is further reduced by one-half.

The applications of HPCF are different from those of GPCF. Special applications include fiber reinforcements for lightweight, high rigidity composites with zero coefficients of thermal expansion for space use and C/C for aircraft brakes, lightweight missile components, and some durable sporting goods. The number of applications will increase with decreasing cost of HPCF. Thus, increasing utilization of high-performance fibers is expected in the near future.

As for PAN fibers, the current commercial uses are mostly in CF epoxy composites or prepregs for aircraft secondary structures. Many CF-reinforced composites with high-temperature resins, such as PEEK and polyimide, have found numerous applications in elevated temperature environments. New formulations of resin have been made to compensate for the low fracture toughness of the CF composites. Some PAN fibers have been substituted for GPCF for essential structural components such as I-beams and tubes. CF with a very high porosity have been made to use as gas absorbants, as water purifiers, or in toxic substances removal. Pre-oxidized CF fabrics are currently available for fireproof clothing and firefighting equipment. Based on the cost trend and the increasing demand for PAN fibers in recent years, these high-performance fibers may occupy a major role in future structural materials.

FEATURES OF MANUFACTURED PRODUCTS

Producers of PAN-Based Fibers

Toray Industries, Inc. Toray Industries, Inc., is the largest producer of PAN-based carbon fiber with an annual production capacity of 1,500 tons. The corporate research laboratory is well equipped with various research facilities and is actively developing new applications of carbon-fiber-reinforced composites. A wide variety of carbon fibers is commercially available, ranging from a high tensile strength fiber, T1000 (7 GPa), to a high modulus fiber, M50 (500 GPa). An intermediate fiber, such as M46J (with tensile strength and modulus values of 4.2 and 460 GPa, respectively), is also available.

The PAN precursor was produced from the company's own plant. The characteristics and the composition of the precursor polymer are proprietary information. Since the final physical strengths of carbon fibers are strongly dependent on precursor homogeneity, little information was provided concerning the manufacturing process.

The 1985 production capacities for the products of Toray and its licensees (trade name TORAYCA) are as follows:

Toray Industries, Inc., Japan	1,500 tons/yr
SOFICAR S.A., France	300
Amoco Performance Products, Inc., U.S.A.	360
Total	2,160 tons/yr

The products have a wide variety of mechanical characteristics to meet industrial needs. These products are well known and have become commercial standards in the carbon fiber market. The mechanical properties of the TORAYCA products are as follows:

Fiber Type	Tensile Strength (GPa)	Tensile Modulus (GPa)	Elongation (%)
T300	3.53	230	1.5
T400H	4.5	250	1.8
T800H	5.59	294	1.9
T1000	7.00	300	--
M30	3.92	294	1.3
M40	2.74	392	0.6
M40J	4.4	392	1.0
M46	2.35	451	0.5
M46J	4.2	451	0.9
M50	2.45	490	0.5

Toho Rayon Co., Ltd. This company is the second largest producer of carbon fibers in the world. Annual production is 1,420 tons, which is second to Toray, but the total production related to carbon fibers, including oxidation resistant and activated fibers, is more than 1,600 tons. The company has a strong tie with BASF (U.S.A.) for technical and marketing agreements. The majority of the fibers produced are exported to the United States, Europe, and southeast Asia. In southeast Asia, Toho products dominate the market.

I visited the Toho Tokyo office and the Mishima laboratory and had friendly discussions with the director, managers, laboratory chief, and engineers. They are very proud of their products and are currently working on the development of new carbon fiber markets, which include many structural components (concrete I-beams, gears, C/C composites, battery shields, sporting goods, pipes, panels, x-ray beds, and various shaped beams); elastomer-toughened composites; elastomer compounds; and many others. Their central research laboratory was furnished with many up-to-date instruments and research and test facilities. One of the current research efforts on carbon fibers is aimed at enhancing the mechanical strength by increasing the average molecular weight of the PAN polymer (from 10 to 100K) and also by improving the homogeneity of the polymer. Every year there has been improvement in mechanical strength.

The commercial carbon fiber products (trade name BESFIGHT) are not limited to fibers but also include prepregs, woven fabrics, chopped fibers, and felts. The mechanical properties of the fibers are as follows:

Fiber Type	Tensile Strength (GPa)	Tensile Modulus (GPa)	Elongation (%)
ST-2	4.2	240	1.7
ST-3	4.4	240	1.8
HTA	3.7	240	1.0
HM35	2.7	350	0.8
HM40	2.6	400	0.65
HM45	2.2	450	0.5
IM400	4.2	300	1.4
IM500	4.8	300	1.6
IM600	5.8	300	--

Mitsubishi Rayon Co. This company is the third largest PAN carbon fiber producer in Japan. Although its production at the present time (120 tons) is an order of magnitude less than Toray or Toho, the company is rapidly expanding its production capacity to 500 tons next year. This is based on a growing market with more diversified applications.

At the Otake plant and the central research laboratory near Hiroshima I was guided through the acrylic fiber operation. However, the carbon fiber manufacturing line was off limits. The corporate laboratory had many new instruments to facilitate their research efforts, which are concentrated on the improvement of fiber strength, process modification, and the optimum designs for fiber-reinforced composites.

The mechanical properties of Mitsubishi's products (trade name PYROFIL) are as follows:

Fiber Type	Tensile Strength (GPa)	Tensile Modulus (GPa)
T-1	3.8	250
T-3	5.3	250
MM-1	5.4	315
LM-2	5.9	315
LM-5	5.9	345
HM-2	4.7	420
SM-1	3.9	485

Producers of Pitch-Based Fibers

Kureha Chemical Industry Co., Ltd. This company produces general-purpose, pitch-based short carbon fibers for insulation, felts, and reinforcements of plastic materials. The production of low-cost short fibers was 500 tons last year. This year a new plant will increase the capacity to 1,000 tons. This increasing demand arises from extensive use in short-fiber-reinforced concretes, which have mechanical strengths 10 times that of conventional concretes. The corporate research is aimed at pursuing processing techniques and developing high-performance fibers derived from petroleum pitch. The pitch-based, general-purpose fibers are very cost effective reinforcement materials. There are three grades of the product: two carbon grades carbonized at 1,000 °C designated as the T-100 series and a graphite grade treated at 2,000 °C designated as the T-200 series. The cost is about ¥2,000/kg and is expected to decrease to ¥1,500/kg if sales improve.

Osaka Gas Co., Ltd. Osaka Gas has developed new technology (the so-called Cherry process) for producing carbon fibers from coal tar (Ref 27). In the Cherry process, pitches without any quinoline insoluble components are obtained by continuous heat treatment from crude coal tar, which is a by-product of coal-manufactured gas. The process involves three stages of centrifugal separation of impurities (such as free carbon) at high temperatures. The purified pitches are claimed to have high spinnability and softening point and are used to produce continuous filaments after hydrogenation or to prepare short fibers by rotary gas jets. The products are both high-performance and general-purpose fibers designated as DONACARBO-F and -S. The annual production of short fibers for insulation and felts and low-cost reinforcements is 300 tons, while that of the high-grade fibers is only 10 tons. These short fibers are different than the Kureha Co. fibers, which have curved strands and no circular cross section. Thus, the fiber-reinforced composites will provide better electrical and thermal conductivities because of close contacts among fiber strands. Also, a three-dimensional structure can be readily made.

The major objectives of the corporate developments are to: (1) improve fiber strength by decreasing flaws and pore densities; (2) obtain better control of carbonization temperature; and (3) promote fiber orientation by spinning condition and temperature, nozzle temperature and cooling rate, draw ratio and speed, etc. The project manager emphasized that the future outlook of the pitch-based carbon fiber industry is promising due to the low cost of raw materials and the simple processing technology.

The mechanical characteristics of the high-performance fibers are as follows:

Fiber Type	Tensile Strength (GPa)	Tensile Modulus (GPa)	Elongation (%)
F-140	1.8	140	1.3
F-500	2.8	500	0.55
F-600	3.0	600	0.5

Kashima Oil Co. (Petroca). This company is relatively small compared to other Japanese carbon fiber producers. Recently it has undertaken a joint venture with the BASF Celion carbon fiber unit (PAN fiber producer) for cooperative research and marketing. This partnership will accelerate cooperation toward the improvement of the process technology. Petroca produces only high-performance carbon fibers. The process involved in manufacturing was stated as being very unique but details were not provided. The quality of the products was claimed to be superior to other fibers. The commercial products are sold in the United States by BASF, and Petroca management was very quiet about the progress the company has made in recent years.

The data provided by Petroca indicated that the products were slightly better in mechanical properties as follows:

Fiber Type	Tensile Strength (GPa)	Tensile Modulus (GPa)	Elongation (%)
HM50	2.76	490	0.56
HM60	2.94	588	0.5
HM70	2.94	689	0.43

This small oil company was very cautious about our visit because of strong market competition from big producers of chemicals and petroleum in the pitch-based carbon fiber business.

Nippon Petrochemical Co., Ltd. Nippon Petrochemical Co., otherwise known as Nippon Oil, has been a pioneer and leader in the Japanese oil industry and is the largest oil company. Nippon Oil's carbon fiber research began 7 years ago in an attempt to convert huge amounts of pitch to high value added products. This research in carbon fiber processing has resulted in successful fabrication of high-grade pitch-based carbon fibers. The company is moving cautiously into carbon fiber production and is building a pilot plant with a capacity of 10 tons at this moment. If the pilot plant is successful, a full-scale production will soon follow.

I visited the corporate central research laboratory at Negishi near Yokohama. A tour of the research laboratories was arranged, but the carbon fiber production line was off limits. The laboratory was well equipped. The properties of their pitch-based carbon fibers are remarkably different from other types of fibers. In particular, the plastic deformation characteristics at high stress are unique. A bundle of fibers (high modulus) can be knotted and twisted without breaking. This fiber property based on the microstructure, composition, or crystallite orientation is extremely interesting. Four grades of carbon fibers (trade name GRANOC) are available. The differences among these fibers are only in the treatment temperatures. The mechanical properties of the fibers are as follows:

Fiber Type	Tensile Strength (GPa)	Tensile Modulus (GPa)	Elongation (%)
XN-40	3.23	390	0.83
XN-50	3.23	490	0.66
XN-60	3.23	590	0.55
XN-70	3.3	690	0.49

Toa Nenryo Kogyo K.K. Co. This is the third largest petroleum refining company in Japan. Toa began exploratory research on pitch-based carbon fiber in 1976 and has succeeded in fabricating high-quality pitch-based fibers. Although no commercial product was available at this time, test samples were available in the past year. The advantages of Toa's processing are: (1) efficient mesophase pitch process, (2) high purity and low viscosity precursor pitch, (3) innovative spinning and drawing processes, and (4) advanced and efficient carbonization processes. Since the future success of the carbon fiber industry is dependent on the efficient preparation of raw pitch precursor and a simple processing technique, the research along this direction in my opinion is highly crucial. The mechanical properties of the available carbon fibers are as follows:

Fiber Type	Tensile Strength (GPa)	Tensile Modulus (GPa)	Elongation (%)
UHM	3.8	730	0.5
HM	3.2	515	0.6
HT	3.0	270	1.1

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Sin-Shong Lin, who received a Ph.D. from the University of Kansas in 1966, has been employed by the Army Materials Technology Laboratory at Watertown, MA, since 1967. Dr. Lin's research interests include chemical thermodynamics, phase diagram, high temperature syntheses, mass spectrometry-atmospheric sampling, and surface analytical techniques (x-ray photon and Auger electron spectroscopies) for material characterizations (of interest are titanium mixed oxides, silicon nitride, gun steel erosion, rubber-elastomer, and carbon fiber). Currently he is active in the fields of surface modification and characterization of carbon fibers. Dr. Lin is a member of the American Chemical Society, American Vacuum Society, Electrochemical Society, Material Research Society, and Carbon Society.

SECOND INTERNATIONAL SYMPOSIUM ON BIOELECTRONIC AND MOLECULAR ELECTRONIC DEVICES

E.S. Chen and A.F. Findeis

The technology necessary for some bioelectronic and molecular electronic devices is approaching reality. At the symposium in Fujiyoshida, Japan, the focus was on understanding information processing and development of molecular and bioelectronic assemblies. A view of the present status and future prospects of the technology was presented.

INTRODUCTION

The R&D Association for Future Electron Devices is an organization of the Ministry of International Trade and Industry responsible for the management of research programs on the National R&D Project on New Electronic Devices. This project focuses on four areas of scientific activity: (1) "Superlattice Devices" (implemented in 1981), (2) "Three-Dimensional ICs" (1981), (3) "Bioelectronic Devices" (1986), and (4) "Superconducting Devices" (1988). Symposiums are held on a regular basis as a means of reviewing research progress and to disseminate results to the Japanese industrial community.

On 12-14 December 1988, the R&D Association for Future Electron Devices held the Second International Symposium on Bioelectronic and Molecular Electronic Devices in Fujiyoshida, Japan. The focus of this symposium was on two research themes: the development of molecular and biomolecular assemblies and the understanding of information processing in living organisms. The symposium had over 138 registered participants, a large number of whom were from industry. The technical program consisted of 39 presentations from three countries: seven from the United States, one from Israel, and the remainder from Japan. Highlights of most of the papers are discussed.

ORGANIZED ASSEMBLIES OF SYNTHETIC MOLECULES

The Langmuir-Blodgett (LB) method involves the formation of an ordered monolayer film on a liquid subphase and the transfer of the film to a solid substrate. The LB method, with over 50 years of development, is an important process for growing multilayer molecular assemblies. However, there are many concerns. These include the need for a better understanding of (1) the relationship between the film transfer process and film quality, (2) initial intralayer and interlayer bonding for structural stability, and (3) the effective control of molecular arrangement in multilayer assemblies.

Miura et al. of Toshiba Research and Development Center investigated the dependence of surface pressure on the dynamics of film transfer for the aluminum stearate-water, silicon substrate system. They reported two interesting observations: (1) the static surface pressure, π_o, the pressure before film transfer, can have an appreciably different value than the dynamic pressure, π_e, at the moving substrate during film transfer, and (2) the surface pressure at various locations away from the moving substrate can have values ranging between zero and π_o. Since surface pressure is related to packing order within the film and π_o is usually associated with the highest packing density, lesser values of surface pressure reflect a higher state of disorder in the film. The key issue is monitoring π_s during film transfer. Under the condition of $\pi_s \simeq \pi_o$, Miura synthesized LB films of aluminum stearate with a higher order of molecular continuity and orientation than films produced at $\pi_s << \pi_o$.

Sagiv of the Weizmann Institute of Science, Israel, reported on the construction of organized multilayer structures through chemically controlled self-assembly (CCSA). The CCSA approach combines the self-assembly technique based on the work of Zisman in 1946 on the formation of oriented monolayers by adsorption from solution with methods of in-situ chemical modification of the preassembled structures. Over the past several years, Sagiv's group has demonstrated that planned assemblies similar to those built by the LB method can be obtained by the adsorption of n-octadecyltrichlorosilane (OTS), hexadecenyltrichloro-silane (HTS), and similar compounds on immersed silicon and aluminum substrates. The attractive features of the CCSA approach include (1) strong covalent bonding of the initial layer to the substrate; (2) improved interlayer bonding by chemically modifying the terminal end of the adsorbate, i.e., oxidize terminal vinyl groups in HTS to hydroxyl groups to effect chemisorption; and (3) minimized propagation of defects in imperfect surfaces with "gap bridging" compounds like OTS. Multilayer structures were synthesized to demonstrate the feasibility of the CCSA process. The use of compounds showing optical, electrical conduction, and other properties has yet to be demonstrated.

Tanino et al. of the Electrotechnical Laboratory, Tsukuba, reported on the selective coordination epitaxy (SCE) procedure to make artificial molecular assemblies. Unlike the LB method, which is restricted to long hydrocarbon chain materials, the SCE procedure uses the chemical nature of coordination bonds in metal complexes to selectively form oriented structures. Halogen-bridged mixed-valence metal complexes, i.e., $[Pt(II)(en)_2]$ $[Pt(IV)Br_2(en)_4](BF_4)_4$, and many metal complexes, i.e., porphyrins, dialkylglyoximes, phthalocyanines, can be grown by liquid- or vapor-phase SCE. Growth of single and double heterostructures with three-dimensional ordering has been demonstrated.

An important area of study in LB films concerns the influence of molecular orientation on film properties and applications. Kawabata et al. of the National Chemical Laboratory for Industry, Tsukuba, reported on characterization of LB films of amphiphilic cyclodextrins and host-guest LB films of cyclodextrins and azobenzene. Cyclodextrins with a central cavity in the molecule having a diameter from 6.0 to ?.4 Å can accommodate a number of organic molecules to form an ordered system. They showed that the host-guest arrangement enabled azobenzene to undergo reversible, cis-trans photoisomerism. Without the host, LB films of alkylazobenzene do not show reversible transformation. The cavity provides favorable free volume for the transformation without steric hindrance. Host films have potential molecular-electronic applications in the area of recognition of guests as well as in optoelectronic devices.

Yoneyama et al. of the Research Center of Mitsubishi Kasei Corporation described a novel approach to forming LB films of rhodamine dye derivatives at an air-water interface. The approach follows the procedures of Kawabata on the forming of LB bilayers by controlling the surface pressure applied to mixed monolayer films. For the system of rhodamine dye and arachidic acid, the bilayer that is formed at a surface pressure above 30 mN/m is interpreted by Dr. Yoneyama as resulting in the rhodamine derivative being squeezed out of the mixed monolayer film. The ultimate structure of the displaced rhodamine dye molecules shows a strong dependence on the acidity of the subphase. At low pH, the rhodamine is squeezed out in the form of the unionized cation. At high pH, the displaced rhodamine favors the structure of the ionized zwitterions with subsequent rearrangement to lactone. The identification and characterization of functional molecules exhibiting the properties of pressure-induced isomerism are goals of future studies.

Miyake et al. of the Fermentation Research Institute, Tsukuba, examined the response of photosynthetic membranes containing cells of bacteria *rhodopseudomonas veridis*. They measured the adsorption spectra of the membranes in the dry state and in an aqueous environment and found little difference in the spectra. Flash-induced photocurrents were also observed in both the wet and dry films. These results verify the utility of using naturally occurring biomolecules to function in a nonphysiological environment.

Fujihara of Tokyo Institute of Technology presented a study in biomimetic photoresponsive assemblies that function as photodiodes. The artificial photosynthetic monolayer consisting of perylene sensitizer (S), viologen electron acceptor (A), and ferrocene electron donor (D) units was prepared by the LB technique on semitransparent gold electrodes. Antenna pigments of pyrene were also added to harness light energy to the ASD triad as a mixed monolayer. Both a direct excitation mechanism of energy transfer in the ASD monolayer film and an additional energy transfer in the mixed monolayer from the antenna pigments to the ASD triad were evident. The photocurrent intensity can be affected by changing the distance between the A-S-D units and by varying the molecular orientation by using different surface pressures during the LB film transfer. Thus, increasing the carbon chain length connecting the A, S, and D units and increasing the surface pressure increased the photocurrent by a factor of 20. However, the quantum efficiency was only about 1 percent. Quenching of the excited species by the gold electrode and the unoptimized alkyl chain lengths are thought responsible for the low quantum efficiency.

INFORMATIONAL NEUROSCIENCE

Matsumoto of the Electrotechnical Laboratory, Tsukuba, reviewed current research on neurocomputing noting that the limitations originate primarily from the oversimplification of modeling neurons. Current models of neural networks are based on mathematical descriptions that use a large number of homogeneous and simple connectionist processing elements. In reality, neurons are not homogeneous and a variety of functionally different neurons exist. Furthermore, neurons show powerful processing versatility as demonstrated by dynamic molecular transformations that occur in response to external stimuli.

Matsumoto likens real neurons to LSI microprocessors with a kind of memory function similar to a digital computing system and recommends the consideration of this view in research strategies.

Indicator dyes have the unique characteristics whereby their absorbance and fluorescent properties can change in response to changes in pH, surface potential, and other environmental conditions. These dyes have been used to good advantage to monitor intracellular changes in the study of neural functions. Ross of New York Medical College discussed optical methods of recording electrical and calcium events in neurons. Voltage-sensitive dyes respond to a change in potential across cell membranes and, with suitable imaging procedures, can be used to identify action potentials occurring in individual cells. The propagation of potential across the cortex was recently demonstrated in recordings of brain activity. Calcium indicator dyes are used in two ways. One is to study the role of calcium as intracellular messengers by tracking changing calcium levels. The other is to use the variation in calcium following a calcium action potential as a measure of electrical activity. The optical approach can be extremely effective in revealing information about large neural structures, groups of interacting neurons, and regional properties of individual cells.

Fluorescent imaging of regional changes in Ca^{+2} ion concentration within a neuron is essential to the understanding of information processing and storage in neurons. Using this approach, Iijima and Matsumoto of the Electrotechnical Laboratory, Tsukuba, obtained depolarized and hyperpolarized responses from neurons of rat hippocampus stimulated with equal doses of acetylcholine. These responses have been interpreted as three types of connections between the acetylcholine receptive site and the ion channel.

Analyses of Ca^{+2} ion concentration were also used by Kudo and Kato of Mitsubishi Kasei Institute of Life Sciences to study the mechanism of long-term potentiation (LTP), which has been postulated to depend on the level of Ca^{+2} ions. Tetanic stimulation (50 hertz, 1 to 5 seconds) on rat hippocampal slice preparations produced regional elevation of Ca^{+2} ion concentrations lasting over 2 minutes. The increase in Ca^{+2} ion concentration reveals the distribution of synaptic input into these areas from the stimulated pathway. On the other hand, stimulation with N-methyl-D-aspartate produced even higher levels of Ca^{+2} ion concentrations without an effect on LTP, suggesting factors other than Ca^{+2} ions can also influence LTP. Drug-induced propagation of population spikes is one consideration.

Shiono et al. of Mitsubishi Electric Corporation applied a multichannel optical recording method to study the abdominal ganglion of a sea mollusk, Aplysia, during gill withdrawal reflex. The work, which involved an analysis of the whole ganglion, follows the experimental procedures reported by Wu et al.* In Wu's study optical measurements were made on a part of the ganglion adjacent to the siphon. Shiono reported the detection of 37 active neurons showing excitatory or inhibitory effects and the tentative identification of 11 of the neurons. They will continue the optical approach along with electrophysiological techniques to analyze the dynamic aspects of neural networks controlling gill withdrawal reflex.

*Wu et al., *Experimentia* **44**, 369 (1988).

Siddiqui of Toyohashi University of Technology reported on a study to distinguish the neural network mediating touch sensitivity in the *Nematode Caenorhabditis elegans* using immunocytochemistry. The nematode has six touch receptor cells, three of which are located in the anterior region and the remainder in the posterior region. These touch receptors show a strong position dependent response to neural antigens. Applications of a neural antigen to the touch receptors produced staining involving only the three anterior cells. However, in the presence of a mutant *mab 5*, the postembryonic ventral microtubule (PVM), a touch sensitive receptor from the posterior set, was also brightly stained along with the anterior set. Evidently, the mutant caused PVM to assume a more anterior position by inhibiting the posterior development of the PVM precursor. The significance of the position dependent response relates to the importance of cell-cell interaction in the formation and function of neural networks. The nematode was selected for study because a description and identification of the entire nervous system, all 302 neurons, has been established. Thus correlations with immunocytochemical studies can reveal cell formations that are not obvious through anatomical connections alone.

ORGANIZED ASSEMBLIES OF BIOMOLECULES

The use of proteins in synthetic membranes and organized assemblies poses a number of questions regarding the behavior of proteins at an interface. Andrade of the University of Utah reviewed the mechanisms of protein adsorption, citing a number of hypotheses that are now accepted and being tested. Proteins possess multiple hydrophilic and hydrophobic binding sites. This characteristic together with the ability of proteins to undergo conformational changes led to adsorption irreversibility as opposed to that observed in single binding site Langmuir-type adsorption. The adsorption of mixed proteins is time and concentration dependent. For short times, the surfaces will be populated quickly by the species with the higher collision rate. On aging, a competitive process occurs with the accommodation of the proteins with the higher adsorption energy. Also, the adsorbate or the protein molecules can be altered with steric exclusion modifiers to regulate adsorption.

Kagawa et al. of Jichi Medical School presented a study on membrane electronics of reconstituted thermophilic proteins. Their work consists of two parts: (1) measurement of the electrical activity of ATP synthase in a lipid bilayer system and (2) construction of an ISFET micro-ATP sensor. The bilayer system was made by fusing ATP synthase liposome to a planar lipid bilayer. They calculated a proton/ATP stoichiometry of 3 for ATP synthase as opposed to the value of 2 reported in the literature. ATP is important in living cells and one can determine the number of cells by measuring the ATP concentration. With respect to ATP biosensors, Kagawa reported that the lipid bilayer is too unstable to be of practical use. The micro-ATP sensor consisting essentially of the catalytic portion of ATP immobilized on the surface of an ISFET holds greater promise. The performance of the micro-ATP sensor is characterized by a linear semilogarithmic relationship between the initial rate of differential gate voltage change (1 to 4.5 mV/min) and ATP concentration (0.2 to

1.0 mM). Additional improvements are anticipated by modifying the catalytic properties of the proteins through site-directed mutagenesis.

Ishibashi et al. of the Hitachi Advanced Research Laboratory reported their work on the photoreaction of octopus rhodopsin (OR) immobilized by (1) entrapment in polyacrylamide gels, (2) adsorption on nitrocellulose membranes, and (3) LB film transfer onto quartz slides. In solution, OR is photosensitive and transforms reversibly between rhodopsin and metarhodopsin on exposure to blue and red light, respectively. In the bound state, OR entrapment in polyacrylamide gel retains photoreversibility. OR adsorbed on nitrocellulose membranes shows photoreversibility in water but not in the dried state. LB films of OR on quartz did not have measurable adsorbance apparently because of the stacking instability of the LB films. Ishibashi stressed that while entrapment and adsorption procedures appear viable, they are inappropriate for producing oriented structures. The more promising approach of combining self-assembly with the LB method was proposed. The procedure involves the synthesis of antibodies with molecular recognition sites at opposite ends. One end will facilitate binding to the initial lipid monolayer to produce ordered arrays of antibodies while the opposite end will attract rhodopsin. Organized assemblies can then be constructed of a lipid monolayer, intermediate self-assembled oriented antibodies, and adsorbed rhodopsin.

Isoda et al. of the Central Research Laboratory, Mitsubishi Electric Corporation, applied FT-IR and visible YAG laser time-resolved spectroscopic measurements to study the molecular orientation of flavin and porphyrine LB films and the electron transport function of flavin and cytochrome c in organized molecular assemblies. From an analysis of transient absorption spectra for the flavin/cytochrome c/EDTA solid film, the electron transport from flavin to cytochrome c is found to be an ultrafast process with a rate constant of about $5 \times 10^{8} s^{-1}$. From electrode potential considerations it appears that electron transfer from flavin to cytochrome may be unidirectional, being energetically favored over the reverse direction. Isoda verified this to be the case by electrolyzing flavin LB electrodes in cytochrome solutions; no essential oxidation reactions occurred in the potential range between -0.1 and +0.5 volt (versus Ag/AgCl), while reduction was observed at a potential more negative than -0.3 volt. Isoda concluded that flavin shows rectifying characteristics and may be useful in functional LB assemblies for the directional regulation of electron flow.

CROSSROAD OF ARTIFICIAL INTELLIGENCE, NEURAL NETWORK, AND PARALLEL PROCESSING

The ultimate aim of computational neuroscience is to explain how chemical and electrical signals are perceived and processed in the brain. Over the past decade, significant advances in computer capabilities and increased knowledge of brain functions produced an extraordinary growth of interest in neural models and computational properties. Aiso of Keio Gijuku University reviewed the current state of artificial neural network technology and the resulting challenges to scientists working on molecular electronic devices. The author, who is a principal organizer of the Fifth Generation Computer project, believes that these networks can be implemented in VLSI circuits to represent biological brain functions in the storing and processing of information and the ability to solve problems. Artificial neural networks are electrical or optical circuits that simulate biological neurons.

Using ionic current considerations in membranes, Usui of Toyohashi University of Technology constructed a Hodgkin-Huxley-type model of the luminosity-type horizontal cell to investigate the spatio-temporal properties of the outerplexiform layer of the retina. The effectiveness of the model to simulate physiological processes of this layer, such as the dynamic characteristics of transmitter release from the photoreceptors, the changes of ionic currents in the horizontal cell, and the reciprocal interactions of horizontal cells through gap junctions, was discussed.

Ito et al. of NHK Science and Technical Research Laboratories reported on the implementation of a multilayered neural network, NEOCOGNITRON, on a parallel computer, NCUBE, for pattern recognition. The neural network was previously simulated on a digital computer and reported at the First International Symposium on Bioelectronic and Molecular Electronic Devices in 1985 as having the capability of providing position-invariant response. In the present study, the characteristics of NEOCOGNITRON were analyzed in terms of parallel processing; the structure of parallel processing, node-assignment, and data transmission were described. Input patterns and dynamic load balance in parallel processing will be the focus of continuing studies.

In other studies relating to information processing, Okajima and Fujiwara of the Fundamental Research Laboratory, NEC Corporation, investigated the role of feedback in the visual system. They constructed a feedback system incorporating a layer that analyzes localized spatial frequency of input image and checked its function by numerical simulation. Ohmori of Tokyo University of Agriculture and Technology described the use of a parallel computer system for the simulation of the image processing of neural networks. A system consisting of 64 microprocessors and monitor software was used in the study of the correspondence problem of binocular stereo visual images. Hosogi et al. of Fujitsu Limited discussed a three-layered neural network model for motor learning and control.

BIOELECTRONIC DEVICES

Hong of Wayne State University applied an electrochemical concept of chemical capacitance to interpret displacement photocurrents observed by pulse light stimulation of bacteriorhodopsin membranes. For bacteriorhodopsin, the primary process leading to displacement photocurrents is the cis-trans photoisomerization and rapid charge separation (oriented dipole mechanism). Another contribution arises from the binding and disassociation of protons with bacteriorhodopsin in the transmembrane transport of protons (interfacial proton transfer mechanism). For each proton adsorbed, a counterion is left behind in solution leading to an interfacial charge separation. In both instances the formation and decay of the charge separation is detectable as a displacement photocurrent. Quasi-short circuit measurements used in conjunction with equivalent circuit analyses showed external loading to be a major factor affecting the time course of a displacement photocurrent. Another factor appeared to be the supporting structure itself. The electrochemical concept of chemical capacitance and equivalent circuits is quite general and could be applied to the design of biomolecular optoelectronic devices with a desirable signal time course.

Two papers were presented on approaches to the realization of biomimetic odor sensors. In the first paper, Moriizumi and Nakamoto of the Tokyo Institute of Technology reported on the sensing and identification of different liquors using a quartz-resonator array and a neural network system similar to that used by Runmelhart et al.* A quartz resonator coated with a gas sensing coating responds to gas adsorption by producing a shift in resonant frequency. To those familiar with quartz crystal oscillator techniques in water detection and chromatography as pioneered by W.H. King of Esso Research and Engineering (as called then) about 30 years ago or the cluster of oscillators approach of Tomas Hirschfeld of Lawrence Livermore Laboratories of a few years ago, this research will have a familiar ring. Neural networking with a training algorithm to provide for adaptive learning of environmental variations was used to process frequency patterns generated from an array of sensors. The results showed a high probability of recognition, 92.8 percent, is possible with frequent calibration (adaptive learning) cycles, while a recognition of 73.6 percent was achieved in the absence of calibration. The authors mentioned that improved recognition will require additional studies with more precise discrimination of odor concentration and interfering odors.

In the second paper, Miyoshi et al. of the Central Research Laboratory, Sharp Corporation, described their study on the use of solvatochromic merocyanine dye films in optical odor sensing. Solvatochromism refers to the phenomenon observed in materials whose solutions change color depending on the polar characteristics of the solvent. The color change is also observed for solvatochromic materials in a gas environment. The authors reported results showing a shift in the absorption spectra to shorter wavelengths when organic gases are adsorbed on merocyanine dye films. The magnitude of the wavelength shift increases with an increase in gas concentration and polarity. These results suggest that solvatochromic materials have the potential for being integrated as odor sensors to provide optical patterns for information processing.

Shimidzu of Kyoto University discussed different approaches to the fabrication of functionally molecular materials including (1) the incorporation of functional groups in conducting polymers through chemical and electrochemical polymerization, (2) the synthesis of conducting polymers, and (3) the integration of functional molecules in molecular materials. Shimidzu used the novel approach of forming multilayers of monomeric amphiphilic pyrrole using the LB method and electrolyzing the LB assembly to produce a laminated structure consisting of alternating conducting and insulating layers. The electropolymerized structure was highly anisotropic showing a dc conductivity of 10 orders of magnitude greater in the parallel than the perpendicular direction. More recently, Shimidzu

*Runmelhart et al., *Parallel Distributed Processing*, Vol I (MIT Press, 1986).

demonstrated that conducting polypyrrole and copoly (pyrrole-3-methylthiophene) can be electropolymerized directly from a mixed monomeric electrolyte to form a laminated structure. The electrocopolymerization from a mixed monomeric electrolyte is made possible because of a difference in the deposition potential between polypyrrole and the polymerized copolymer. The value of this approach lies in the ability to control depth profile in the nm scale with the use of a simple potential sweep program.

Electrical oscillations are a common occurrence when lipid analogue-millipore membranes are placed between two cells containing salt solutions at different concentrations. Saito et al. of Oki Electric examined this phenomenon by measuring the potential and resistance of dioleyl phosphate-millipore membranes separating KCl solutions. The measurements showed significant increases in film resistance with decreasing salt concentration differences. SEM examinations revealed differences in the appearance of pore channels in the membranes; membranes exposed to a high salt concentration show relatively open channels while closed pore structures are obtained with dilute solutions. These results were interpreted as being consistent with a model linking the oscillations to a phase change in the membranes. However, the discrepancy between the observed shorter time interval for the oscillations and the longer relaxation time for resistance change with solution concentration needs to be reconciled. The response of these membranes to different chemical substances will be the subject of future studies.

SUMMARY

The Second International Symposium on Bioelectronic and Molecular Electronic Devices provided a forum for scientists of diverse disciplines to exchange information on the current status and future prospects of such devices. At the symposium, three overlapping research areas were evident: computer technology, bioelectronics, and molecular assemblies. These three areas also represent the thrust areas supported by the Japan Ministry of International Trade and Industry (MITI) and the Science Technology Agency (STA). The thrust areas consist of two MITI programs, Fifth Generation Computers (1982-1992) and Bioelectronic and Molecular Electronic Devices (1986-1996), and a STA Molecular Dynamic Assembly Project (1986-1991). In spite of the complexities of integrating researchers from different sciences, the presentations were focused and the multidisciplinary conference was quite successful in bringing a group with such diverse backgrounds in an intense forum for communication.

The aggressive programs of MITI and STA show Japan to be strongly committed to the development of materials, theory, and new concepts in molecular electronic devices. Typical of the government-supported programs, the activities reflect a consolidated effort of government, academia, and industry as evidenced by the participation of such organizations as the Electrotechnical Laboratory, Tokyo Institute of Technology, and virtually all the major electronic companies. Currently, Japan is striving to commercialize the developments from these programs. One such example is the recent commercialization of an odor sensor developed at the Tokyo Institute of Technology. Sogo Pharmaceutical Co., Ltd. will be marketing the sensor under the brand name of "Fragrance Meter SF-101." Again this is familiar since similar devices such as the Gilbarco™ moisture analyzer and the piezoelectric quartz crystal chromatography detectors are commercially available.

Within the past 5 years, there has been a dramatic increase in research interest in molecular devices worldwide. The following examples of meetings reflect this trend:

1985 First International Symposium on Bioelectronic and Molecular Electronic Devices (Tokyo)

1986 Third NRL Workshop on Molecular Devices

1987 International Symposium on Molecular Electronics and Biocomputers (Budapest)

1988 International School on Biostructures (Sicily)

1989 Second International Symposium on Bioelectronic and Molecular Electronic Devices (Tokyo)

1989 Molecular Electronics, Science and Technology (Hawaii)

1990 Biochemistry of Biosensors (UCLA)

By comparison, the level of technological development in Japan is as advanced as any in the world. This sentiment was shared by both the foreign participants and the Japanese scientists. When asked to assess the quality of presentations at this symposium with other international conferences, Dr. Sasabe of RIKEN, who attended the recent meeting in Sicily, commented that the current symposium had a much higher standard.

While much progress has been made in the understanding, construction, and application of biomolecular systems, the difficult task of information processing, energy conversion, and sensors is in its infancy. Dr. Conrad of Wayne State University, who was also present at the 1985 International Symposium in Tokyo, provided a view of progress in the following manner. Prior to 1985, he thought it would require 50 years of development to realize molecular devices. However, after the 1985 meeting in Tokyo, the estimate was revised to 25 years and, following this symposium, appears possible within 10 years.

Edward S. Chen, Associate Director of the Office of Naval Research, Air Force Office of Scientific Research, and Army Research Office (ARO), Far East Liaison Office in Tokyo since December 1986, has been a program manager in the Materials Science Division at ARO in North Carolina since April 1986. He attended Rensselaer Polytechnic Institute where he received a B.S. degree in chemical engineering in 1959 and a Ph.D. degree in physical chemistry in 1964. From 1964 to 1986 Dr. Chen worked at Benet Weapons Laboratory in New York, initially as a group leader studying dispersion-strengthened materials, as Chief of Electrochemical Processing in 1973, and as Chief of the Physical Sciences Section in 1983. Dr. Chen is a member of the Electrochemical Society and ASM. His research interests currently include the relationship between processing parameters and mechanical properties of ceramic and composite materials and electrochemical processing in the electronics industry.

Arthur F. Findeis is director of the Office of Naval Research Far East. From 1967 to 1988 he was with the Division of Chemistry, National Science Foundation, where he was head, Office of Special Projects, and involved with the interface between chemistry and other disciplines. This activity involved managing the Chemistry of Materials and Chemistry of Life Processes initiatives. He received his B.S. degree in chemistry from Capital University in 1952, an M.S. degree from Purdue University in 1955, and a Ph.D. degree in chemistry in 1957. During the period 1970-72 he was a staff associate with the NSF-Tokyo office. From 1984-85 he was Fellow of Churchill College at the University of Cambridge where he worked in the University Chemistry Laboratory on fast atom bombardment mass spectrometry. He is a member of the American Chemical Society and the American Association for the Advancement of Science.

R&M 2000 VARIABILITY REDUCTION PROCESS TRIP TO JAPAN

Frank S. Goodell, Team Leader, and Bruce A. Johnson

Japanese industry, for the most part, has learned to dramatically enhance its manufacturing capability, especially in the area of producing highly reliable products. Much of their success comes from the application of variability reduction technologies such as statistical process control, robust engineering practices (i.e., experimental design and parameter optimization), and quality function deployment (QFD).

INTRODUCTION

The intent of the trip was to gain a better appreciation of the Japanese management approach and their application of these modern technologies so that we may assimilate them in our defense industry. The trip focussed on the F-15J aircraft. This allowed us to compare the Japanese and American production processes using the same design. We visited four Japanese companies licensed to manufacture the F-15J: Mitsubishi Heavy Industries (MHI), Mitsubishi Precision Company (MPC), Mitsubishi Electric Company (MELCO), and Ishikawajima-Harima Heavy Industries (IHI). We also met with the Japanese Defense Agency (JDA), the Japanese Equipment Bureau, and the Union of Japanese Scientists and Engineers (JUSE). Our itinerary was as follows:

Day 1	JDA, Japanese Equipment Bureau, and JUSE
Day 2	MHI (Oye, Komaki South, and Komaki North Plants
Day 3	MPC and MELCO (Kamakura Works)
Day 4	IHI (Mizuho Plant)

JAPAN DEFENSE AGENCY

The Japanese are licensed to build 155 F-15J/DJ and have built 92 aircraft to date with a production rate of 14 per year (McAir production rate for FY88 is 44 aircraft).

The F-15J averages an operational readiness rate of 90.6 percent under flying conditions similar to the U.S. F-15. JDA averaged 25 flying hours per aircraft per month and accumulated 25,174 flying hours over the last fiscal year. The F-15J primary mission is air defense. The major differences between the Japanese and the U.S. aircraft are the following Japanese-developed subsystems: the radar warning receiver, the electronic countermeasures equipment, the rescue radio, and the data link. Each F-15J is scheduled for planned depot maintenance (PDM) every 3 years.

There are some strong indications that the F-15J is more reliable than its American counterpart. Some of the reasons are its simpler mission and the F-15J'S PDM program. The predominant reason appears to be the emphasis on quality during manufacturing and depot activities.

JAPANESE EQUIPMENT BUREAU

In Japan, all new weapon systems for the military are procured through a central Government agency. The Government factory representatives (equivalent to our Defense Contract Administration Service Plant Representative Office) report directly to the bureau and work closely with the program director. Most of the other acquisition policies and practices closely parallel the U.S military acquisition system. The Japanese defense industry follows the same military standards on quality and reliability as the United States. The differences are that the Japanese make the standards work for them and that the standards are incorporated into company policy and practices.

UNION OF JAPANESE SCIENTISTS AND ENGINEERS

Mr. Noguchi briefed us on "The Japanese Total Quality Control." The important points of his presentation are highlighted below. An outline of the history of Japanese quality control (QC) is given in Appendix A.

The Japanese take quality very seriously. Quality is their national objective, and in most Japanese companies quality takes precedence over profit. It is strongly believed that without quality there can be no profit. Another difference is that Japan does not have "quality engineers"; everybody is responsible for quality. Quality is deployed company-wide and the plant manager is ultimately responsible for quality. As part of his duties, the plant manager personally conducts a quality audit throughout his plant twice a year.

In most companies, workers are strongly motivated to belong to a quality circle. Their participation is said to be voluntary, but their involvement will strongly affect their semiannual bonuses (which can account for up to half of their pay) and their promotions. The worker is an active participant in the continuous improvement process. The worker receives about 6 days of QC training every 3 years. The emphasis is on the seven basic QC tools (discussed in more detail in a later section). In Japan, there are about 1,200,000 quality circles, each with an average of 8.2 members.

According to Noguchi, there are two ways to improve quality: through "ingenuity" or through "total quality control" (TQC). The problem with ingenuity is that it requires highly talented and costly technicians, analysis, and statisticians and cannot be practiced by the whole company. Second, ingenuity cannot be maintained. It will not support continuous improvement. TQC is the structured application of statistical techniques throughout the whole enterprise (the company and its suppliers, see Appendix B). Through teamwork, TQC collectively uses the brainpower of all the employees to eliminate defects through continuous improvement of all the processes.

For 25 years JUSE has awarded the top quality companies with the Deming Award. The award is highly coveted and competition is fierce. The awards are presented annually on national television during prime-time.

MITSUBISHI HEAVY INDUSTRIES

The Oye plant is where Mitsubishi manufactures aircraft fuselage components and space equipment. The plant is highly automated with many manufacturing systems, such as milling equipment, customized according to the advice of workers, foremen, and engineers. In most cases, defect detection was built into the system. If a defect was detected during its manufacturing process, the machine would shut down and notify the worker. Other systems incorporated direct feedback systems designed to reduce defects.

The Komaki North plant was the most impressive of the three MHI plants visited. It is a modern, highly automated facility engaged in missile and aerospace engine manufacturing, repair, and testing. The plant's machining goal for 1987 was 5 defective parts per 1000. We observed a milling process with capabilities of one defective part per billion (Cpk* of 2.5) for a rotating part in a rocket engine.

The Komaki South plant is the location of the Japanese F-15 and F-1 final assembly, flight test, and overhaul facility.

Company Policy on Quality

MHI's total quality concepts are:

- To have all employees participate in quality control during all phases from research and development (R&D) to logistics.
- To ingrain into all employees: "My customer is the next person down the line." This forces ownership of the manufacturing process. Inspection is done during the operation and feedback is immediate. This dramatically reduces scrap and rework.
- To continuously improve quality. This is strongly supported by MHI's management philosophy called Kaizen. Quality is first, then production. The Japanese believe that with quality, production and profits will follow.
- To prevent the recurrence of similar defects. This is done by removing the causes.
- To make it happen through thorough education and training programs.

In-House Education and Training Programs

- Employees receive training every 3 years. In the area of manufacturing and engineering the following programs are taught:

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*Cp is a process capability index. It is a measure of dispersion observed in the manufacturing process. Its definition is the ratio of the specification spread to the measured process variability:

$$Cp = \frac{USL - LSL}{6\sigma}$$

where σ is the standard deviation of the process spread, USL is the upper specification limit, and LSL is the lower specification limit.

Cpk is a process capability index that measures both dispersion and location effects. If the process is centered around the target value, Cp equals Cpk.

$$Cpk = \frac{\min(USL - mean, mean - LSL)}{3\sigma}$$

Industrial Engineering	Supervisor & engineer
Kaizen	Engineer & foreman
Fabrication Techniques	Engineer & foreman
Design of Experiments	Engineer
7 Basic Quality Tools	Foreman & Worker

- New employees receive about 6 months of on-the-job training with classroom education on quality. The "freshman" worker is taught the seven basic tools, which include the statistical process control charts.

- Employees are required to have a public license or professional license for certain jobs and advancement. MHI provides an assistance program for self-development.

Vendor-Supplier Control

- Final inspection is done by the vendor at the vendor's plant.

- An in-process inspection at the vendor's plant is required during manufacturing.

- Annual vendor QC surveys are conducted.

- Technical assistance is provided to the vendor.

- Domestic vendor standard parts have one-fifth of the number of defects the imported parts have. Domestic vendors have shown continuous improvement. Domestic defect-per-part rates have decreased from 6 to 2 percent over the last 16 years, while imported (U.S.) manufactured parts had an average defective rate of 12 to 15 percent until about 1983 when they began to improve to 9 percent.

Engineering and Manufacturing

- Fabrication inspections are done during the operation. Direct feedback reduces scrap and rework.

- Computer-aided planning reduces errors in the work orders.

- There is a rotation program for all engineers.

- Computer-aided design and manufacturing (CAD/CAM) systems provide high quality, short flow time, and lower costs than the traditional engineering process.

- The roles of the supervisor and foreman are very different. In Japan, the supervisor is part of the engineering or production process and is responsible for much of the training. On the floor, the foreman is expected to be able to operate all of the equipment.

- Factories are extremely clean because the Japanese believe cleanliness affects quality. It is the worker who must keep it clean (i.e., the worker sweeps the factory floor).

- Workers protect their tools by storing them on rubber mats and covering their drill bits. All parts and products are covered with clear plastic when not being worked on. The threads of finished bolts are covered with plastic sleeves.

- Inspectors are integrated into assembly teams to validate the work and to provide immediate feedback.

- To provide the worker with strong product identification, the company prominently displays pictures of final products.

Kaizen, Quality Control, and Management

- MHI uses the Kaizen style of management, which is discussed at length in a later section.

- There are 600 quality circles in the Oye plant with 100 percent participation. The circles meet once a week on company time.

- The worker suggestion program (Kaizen Teien) received 114,000 suggestions from 1,500 people (76/person/yr), 80 percent of which were adopted. The worker received about $10 a suggestion. There is a budget for two suggestions per worker per month.

- Workers develop and write their own standard operating procedures and coordinate them with the production engineer.

- When a defect is discovered, the procedure is highlighted in red for future emphasis. This provides continuous feedback for the worker.

- Responsibility for a defect is assigned to the group, not the individual, to encourage teamwork.

Examples of process improvements at MHI are given in Appendix C.

MITSUBISHI PRECISION COMPANY

The Kamakura factory manufactures flight simulators; navigation instrumentation; heads-up, communication, navigation, and IFF equipment displays; and missile guidance systems. The work force is composed of 1,000 employees of which 400 are design engineers and 100 are in quality assurance. All employees are permanent employees and are guaranteed life-time employment. For large corporations in Japan, this is a common practice. This is supportive of their corporate motto: "MPC shall contribute to the welfare of the society...." The cost of nonconforming materials is about 1 percent of sales. MPC uses a Kaizen management and training approach that is similar to MHI. MPC has a strong suggestion program. Workers are awarded $4 to $400 for adopted suggestions.

MITSUBISHI ELECTRIC COMPANY

For the F-15, the Kamakura facility produces the ARC-164 ultra high frequency radio, the central computer, the radar, fuel transfer pumps, boost pumps, and electromechanical actuators. The plant tour concentrated on the assembly of electronic subassemblies. The facility also designs and manufactures guided missiles, fire control systems, satellites, fiber-optics transmission equipment, antennas and waveguides, manufacturing sensors and nondestructive test equipment, and composite products.

Company Policy on Quality

- "MELCO strives to help society through business."

- "Quality, price, and delivery period must all be equally considered as important factors; however, our company especially pays attention to quality." As one of the MELCO managers tried to explain, "price and delivery will be forgotten, but quality stays with the customer and will never be forgotten."

Evolution of Quality at Kamakura

- Quality assurance (QA) was introduced in the 1960s as part of the licensing agreements. MELCO started with U.S. military specifications.

- In 1972, MELCO started quality circles. The circles meet once a week on company time with 100 percent involvement.

- In 1982, TQC was started.

Management and Quality Control

- Management philosophy emphasizes Kaizen and the seven basic QC tools. MELCO has a strong QC and skills training program.

- The quality assurance department performs a quality audit every month. Monthly reports on statistical quality performance are sent to the general manager and all the department managers.

- The company goal is less than 2 percent rejection of lot samples and piece parts. Current defective rates at incoming inspections range from 0.6 to 2 percent (2.7 to 6 times improvement over the last 2 years) and 1 percent of the parts fail after incoming inspection (1.4 times improvement over the last 2 years). Take note of the continuous improvement and that the inspection is imperfect.

- MELCO finds failure analysis a necessity to improve quality. Failure analysis is used to identify the cause of failure and to take corrective action.

- MELCO works with suppliers to eliminate failure causes. MELCO invites suppliers to learn incoming inspection procedures but does not train them in quality practices (contrary to some U.S. and Japanese companies).

Education and Training

- Employees receive a basic course in QC introduction and the seven basic QC tools.

- Engineers are trained in statistical QC, design of experiments, and reliability.

- Middle and senior management are trained in quality management.

Engineering and Manufacturing

- All licensed drawing packages were reviewed and many errors were found on U.S. drawings.

- Workers develop their own assembly procedures.

ISHIKAWAJIMA-HARIMA HEAVY INDUSTRIES

IHI produces and overhauls 19 different jet engines including the F100-100 engine. The Mizuho plant is responsible for engine assembly, overhaul, and testing. This plant provided one of the more impressive floor tours on our trip.

Company Policy on Quality

- "It is the policy of IHI to provide products and services of a quality that meets the initial and continuing needs and expectations of the customers in relation to price and in doing so to be the leader in product quality reputation."

Management, Engineering, and Quality Control

- Once again, Kaizen is the dominant management approach. IHI's management is striving to achieve continuous improvement. For example, the cost of scrap and rework for in-house effort is continuously being reduced:

  - 1980 1.0%
  - 1987 0.2%
  - Target 0.0%

- The primary objective is to meet customer expectations.

- IHI introduced TQC in 1974-1975 and won the Deming Award in 1976. Like MHI and MELCO, quality is practiced company-wide. All employees are involved in quality circles.

- We noticed that one company's employee suggestion program was not as productive as another. IHI's response was that it is a management problem.

- Except for the suggestion program, all awards are group awards. This is part of the group-oriented Kaizen concept that emphasizes team building.

- IHI feels there is a close correlation between safety and quality. There has been only one serious injury (an injury in which a worker lost time at work) in the last 43.5 million man-hours.

- Unlike the other companies visited, IHI starts all "freshman" engineers in design, then interchanges them between design and manufacturing. This is a common practice in Japanese industry. The purpose of putting a design engineer on the floor is to ensure that he understands the needs of the workers and the production engineers.

- IHI has produced 275 F100-100 engines and has accumulated close to 175,000 operational hours. In addition to producing the F100, IHI provides the depot overhaul. IHI collected and presented the following data on the IHI-manufactured F100 engine:

Cell rejects:	0
Engine recalls:	0
Claim ratio by MHI:	0.15
Depot return rate:	0.3%
Class A mishaps:	0

- IHI promotes QA for vendors and subcontractors and sometimes provides vendor training.

Quality Control Activity Demonstration

As part of promoting the quality circles, the top quality circles compete for top honors every 6 months. All the judges are from senior management. The most recent winners gave their presentation. The quality circle was composed of five workers from the turbine blade grinding shop.

The quality circle recognized that 0.8 to 3.2 percent of the blades had dimensional defects. They identified three critical processes, and after 6 months of effort they eliminated all defects. The process capability of the three critical processes increased from Cp's of 1.29, 1.23, and 1.07 to 1.92, 1.66, and 1.66, respectively.

The tools used were the Pareto analysis to identify the dominant source of defects, histograms to show the variability, a cause and effect diagram, a simple design of experiment, a scatter diagram, and some good, old-fashioned brainstorming.

CONCEPTS AND TECHNIQUES

Overview of Techniques

The following table summarizes the tools and techniques the four Japanese companies used as part of the TQC program. Most of the data was collected through a questionnaire.

Tool	MHI	MELCO	MPC	IHI
Seven Tools	D	D	M	D
Deming - PDCA[a]	I	I	I	D
Statistical Process Control (SPC)	M	M	I	M
Kaizen Management	D	D	D	D
Quality Circles	D	D	M	D
Simultaneous Engineering	I[b]	N	N	U
QFD	I[c]	I	N	U
Design of Experiments	I	M	N	I
Parameter Design	N	I	N	U
FMEA/FMECA/FTA[d]	M	M	I	U
Just-in-Time	I[b]	I	N	U
Poke-Yoke	I	I	N	M
Group Technology	N	I[b]	N	U
Flexible Manufacturing	I	M	N	U
Quality Audit	U	U	I	M
Vendor QC	I	U	I	I

D - Dominant contributor; affects all operations and employees.
M - Major contributor to quality.
I - Plays an important role in quality.
U - Unknown; data not available.
N - Not used.

[a]Dr. Edward Deming's ''Plan, Do, Check, and Act'' managerial cycle for continuous improvement.
[b]Limited to a few applications.
[c]MHI applies a similar approach.
[d]Failure modes effects analysis/failure modes, effects, and criticality analysis/fault tree analysis.

Kaizen

Kaizen means incremental improvement. It is the dominant management strategy that emphasizes continuous improvement and involves everyone through teamwork. Unlike the western management style, it is process oriented and requires and fosters good worker-management relationships. Improvements are long term, long lasting, and undramatic. Change is gradual but continuous and constant. Underlying the Kaizen strategy is the recognition that management must seek to satisfy the customer and serve the customer's needs if a company is to stay in business and make a profit. Quality comes first--not profit. Profit will come with quality.

Most of the small improvements come from the Kaizen Teien--the workers' suggestion system. Japanese management makes a concerted effort to involve employees, and the suggestion system is an integral part of the management system, fostering communication from the bottom up. The number of workers' suggestions is an important criterion in reviewing the performance of the workers' supervisors. The average worker in most of these companies provides 50 to 70 suggestions a year, and about 80 percent are adopted. Rewards for an adopted suggestion range from $4 to $400, depending on the company and the suggestion. The average award is around $8.

Teamwork and good human relations are important factors of the Kaizen philosophy. Most of the large process improvements are results of teamwork and small group activity. An important part of team building is the assignment of people to the following activities:

- Quality Circles: Floor workers from each shop meet weekly for 1 hour on company time to discuss manufacturing problems and improvements. The workers are skilled in the seven basic quality tools, and they use these tools to resolve the floor problems and improve the processes.

- Kaizen Group: Multidiscipline teams, composed of skilled workers, foremen, and engineers, resolve the more difficult problems and implement the more challenging improvements.

- Expert Group: Technology improvements are implemented by a special team of engineers. Some of the advances observed were custom-made tooling, such as a fuselage skin polishing machine at the Oye plant.

An important part of the Kaizen management philosophy is that top management is responsible for innovation. Middle management and supervisors are responsible for improvement of the process, and the supervisor and workers are responsible for maintaining the process. Without maintaining the process, there can be no improvement. Therefore, management must establish the policies, regulations, directives, and procedures, and the worker is responsible for following these standards. If workers are able to follow the standards and do not, management must instill discipline. If workers cannot follow the standards, then management must provide the training or revise the standards so workers can follow them. Reprimands are rarely given to an individual. It is a team effort and the team or group receives the admonishment.

Some of the other observed Kaizen concepts were "anonomation," where machines are designed to detect their own defects, policy deployment, quality audits, and total productive maintenance. Total productive maintenance is a form of preventative maintenance for manufacturing equipment and tooling, and much of the remarkable factory cleanliness is attributed to this element of Kaizen.

The Kaizen approach to management and quality consumes about half of the middle and senior management's time. Japanese leadership has made the commitment to quality.

Seven Basic Quality Tools

These tools are an integral part of Kaizen. In all four companies, every worker was taught how to use these tools to continuously improve the production processes. In several of these companies, the workers receive a refresher course every couple of years. The seven basic quality tools are as follows:

- Statistical process control charts are used to monitor a critical manufacturing process and identify the presence of large variations in the process. They are also used to verify that a source of variability has been eliminated.

- Flow diagrams are used to understand production processes and identify critical processes.

- Cause and effect diagrams are used to facilitate problem solving and help in identifying sources of variability.

- Histograms are used to display valuable statistical information such as the distribution of a process variability.

- Pareto diagrams are used to identify the most important causes of variability.

- Scatter diagrams are used to observe the relationship between data.

- Check sheets are used to collect data.

Design of Experiments

Design of experiments is a rigorous statistical experiment used to understand the effects various factors have on a process. Three of the four companies used design of experiments to identify the causes of variability.

Quality Function Deployment

Although QFD (often referred to as quality deployment) is an integral part of Kaizen, its presence was difficult to detect. Most of the operations we observed were producing American designs under license; therefore, the companies did not have the opportunity to apply QFD. MELCO applies QFD to production process design and quality program planning. Although MHI Kobe Shipyard and Engine Works invented QFD, Nagoya Aircraft Works does not use QFD in its formal sense. Instead the Aircraft Works uses a similar technique that is part of its value engineering process.

Poke-Yoke

Poke-Yoke is a structured approach to foolproofing the manufacturing process and is used extensively to prevent defects. Poke-Yoke was used by three of the four companies we visited. Examples include presorted part bins for assembly, transparent tool bins, and the use of special jigs that prevented the worker from assembling the unit incorrectly. The presorted part bin contains only those parts required to assemble one unit. When the bin is given to the worker, the worker can visually verify that all required parts are present. When assembly is complete, the worker will know that all the parts were used because the bin will be empty. Once the bin is empty, the worker will know that the assembly is complete because all parts were used. Transparent tool bins allow for quick visual accounting of tools. This is especially important during engine assembly and repair. The special jigs were developed from workers' suggestions and were designed to prevent incorrect assembly or damage during drilling or other machining processes.

Inspections

Traditional inspection-oriented quality control is being replaced with process-oriented quality assurance. The inspection process is being moved from the product to the process, and when a process becomes fully capable, the noncritical inspections are being eliminated or reduced to sampling. All the companies had incoming inspections, but there is an effort to reduce these inspections through vendor quality control, which is supported by JDA.

SUMMARY

The Japanese take quality very seriously. It is a national objective. All four companies we visited have achieved company-wide quality control and are pursuing vendor quality control. In three of the four companies, every employee was involved in a quality team.

The Japanese military procurement system is similar to our system except that Government and industry have a better understanding of the importance of quality.

Both U.S. and Japanese Government quality and reliability standards are incorporated into company policy and practices.

The Kaizen management approach is instrumental in achieving quality for these Japanese companies. Kaizen is a process-oriented approach that nurtures team building and continuous improvement. The key to Kaizen is that management puts quality first. The reason the workers' suggestion system and the quality teams work is because management makes them work. These two institutions are significant reasons why the Japanese can achieve continuous improvement in the factory.

Senior management is directly involved in quality. In several of the plants, the general manager or president personally conducts his own semiannual quality audit.

Teamwork and good human relations affect quality. Reprimands are rarely given to an individual--it is a team effort and the team or group receives the additional training or admonishment.

Another significant finding is that the workers control their environment. They write or assist in writing their own standard operating procedures. This gives the worker a sense of responsibility and ownership for his work. With quality training, the worker can influence the quality of his processes and products with minimal supervision.

Lastly, we found that the variability tools and technologies played an important role in eliminating scrap and rework and are a significant contributor in the F-15J's high reliability.

RECOMMENDATIONS

The trip validated our strong belief in the variability reduction process (VRP) technologies and we need to continue to foster VRP awareness and commitment. We learned how the seven basic tools can be used by the worker and the collective effect employees could have on a weapon system.

We gained a special appreciation for the Japanese management style and commitment to quality. We need to convince our senior leadership to undertake the same commitment, assimilate some of the Japanese managerial techniques that are suited for our culture, and assimilate more ideas as the attitudes change. Much of this can be accomplished through R&M 2000 and Total Quality Management initiatives.

We need to change our cultural attitudes towards quality. When done correctly, we saw how quality improved reliability and safety and lowered cost. We need to make the commitment for continuous improvement and to tear down the managerial and functional barriers to quality. This can only be done through education, training, and application.

Brigadier General Frank S. Goodell was the Special Assistant for Reliability and Maintainability to the Military Deputy for Acquisition, Office of the Secretary of the Air Force, and to the Deputy Chief of Staff for Logistics and Engineering, Headquarters U.S. Air Force, Washington, DC. He received a B.S. degree from Ohio State University and an MBA from Auburn University and is a graduate of the Naval War College. GEN

Goodell has received the Society of Logistics Engineer's 1987 Founders Medal, American Society for Quality Control's Outstanding Accomplishment Award, and the United States Air Force's Distinguished Service Medal for his contributions to engineering, manufacturing, and logistics. The General is a command pilot with over 4,000 flying hours. His previous assignments include Ogden Air Logistics Center, where he was Director of Plans and Programs and later the Director for Material Management. GEN Goodell retired from active duty on 1 February 1989.

CAPT Bruce A. Johnson is a staff officer assigned to the Office of the Special Assistant for Reliability and Maintainability and is responsible for implementing the Air Force's Variability Reduction Process. He received a BSEE from the United States Air Force Academy and an MSEE from the Air Force Institute of Technology. His prior experiences include project engineer on the Adaptable Surface Interface Terminal of the Joint Tactical Information Distribution System and Executive Officer to the Deputy for Tactical Systems at Electronic Systems Division.

Appendix A

HISTORY OF JAPANESE TOTAL QUALITY CONTROL

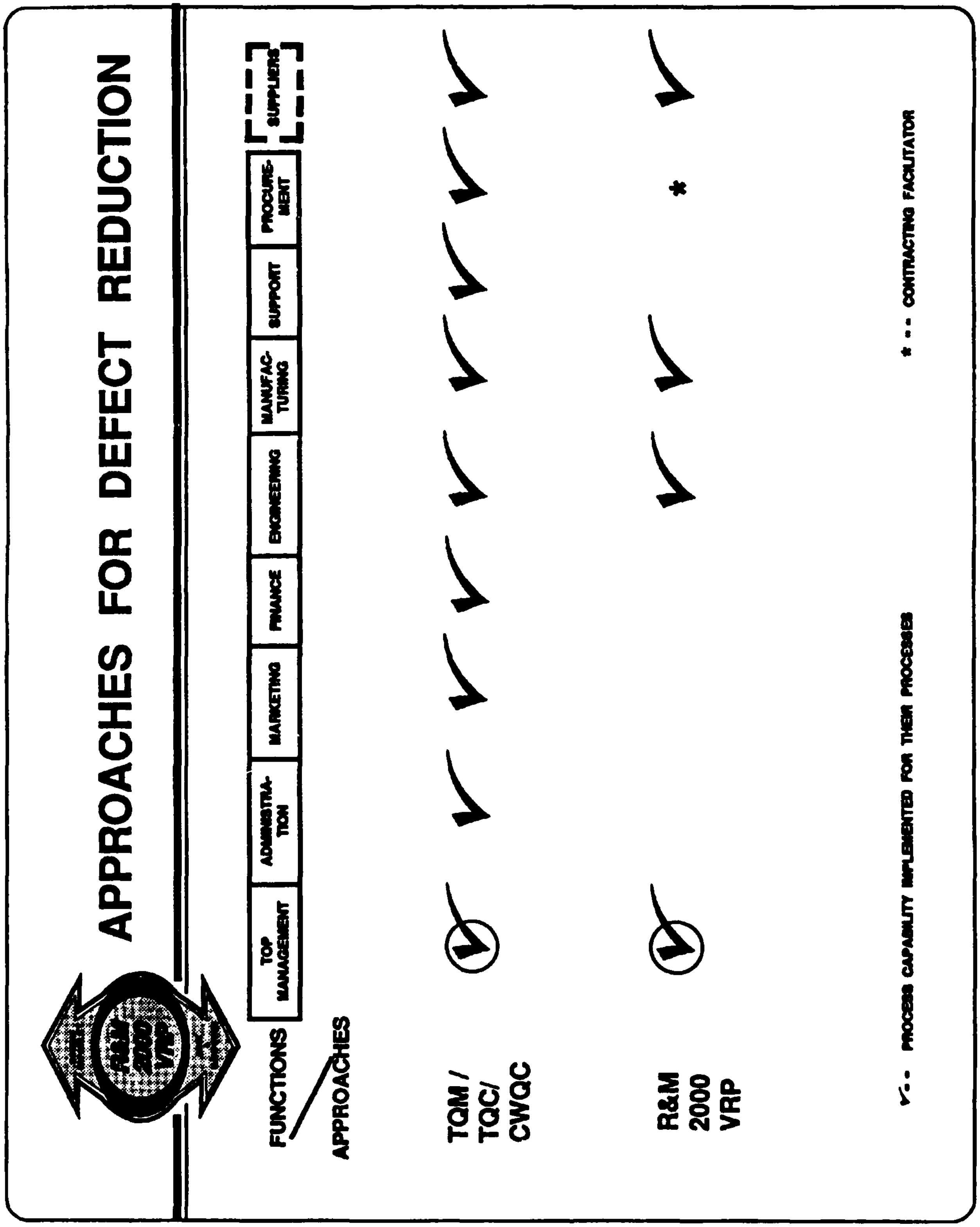
Date	Event	Focus
1950	Statistical Quality Control • Introduced by Dr. Deming	Engineering and production
1955	Management Quality Control • Introduced by Dr. Juran; taught how to combine QC with management	Top and middle management
1960	Foreman Quality Control	Foreman and the workers
1965	Total Quality Control (TQC) • Started at Toyota • Changed inspection point from acceptance to the production process • Just-in-Time is an outgrowth of TQC	All other departments company-wide QC
1970	Vendors' Quality Control	Subcontractors--small to medium companies
1975	Construction Quality Control	Nonmanufacturing industry
1980	White Collar Quality Control	Service industry

Significant Events:

1945-1950	Post-World War II--Japanese industry had to rebuild with only one resource--people.
1953	End of the Korean War--Industry was rocked by the termination of U.S. military contracts. Japanese industry was reacquainted with the reality that Japan had few resources other than its people, and that they must develop manufactured goods for export to raise capital and the standard of living.
1973	OPEC Oil Crisis--Before the crisis, TQC stagnated. This is most apparent in the reduction of Deming Awards prior to the crisis. But the crisis reignited the TQC movement as a way for industry to stay competitive.

Appendix B

APPROACHES FOR DEFECT REDUCTION



Appendix C

EXAMPLE OF PROCESS IMPROVEMENTS

D-1. F-15 Speed Brake (MHI)

Product #1	7 defects (tags)	Product #71-80	0.2 defects/brake

Improved the manufacturing process through the seven basic tools and Kaizen suggestion program. Improvement program also eliminated most hand-finishing after honeycomb carving. The speed brake is still hand-finished in the U.S.

D-2. Boeing 747 Flap Assembly (MHI)

1. Improvement process

- Reviewed historical data; Fairchild had built 700
- Checked Boeing drawing (20 years old)
- Suggested over 400 improvements
- Boeing accepted 200 improvements
- Used CAD techniques and converted to CAD drawings

2. Results: Eliminated rejects.

D-3. Patriot Canister–Preproduction: Arc Welding (MHI)

Old method--Could not control the weld current, which resulted in a high defect rate.

New method--Based on a suggestion, they installed a camera for real time feedback and were able to control weld current. Results: eliminated weld defects.

D-4. F-15J Quality Assurance Activity Results at MHI

Squawks (defects) per aircraft during flight testing and checkout:

Production F-15J:	#3-17	#18-47	#48-68	#69-81	#82-98
Squawks/aircraft:	270	220	140	70	50

Quality trends for machined parts (Komaki-North plant):

Defect Rate	**1983**	**1985**	**1988**
Vendor	2.0%	1.0%	0.6%
In-House	1.9%	1.6%	0.3%

CARBON AND ADVANCED FIBER ACTIVITY IN KOREA

Edward M. Lenoe

In the past few years there has been a great deal of activity in the advanced composite fiber and whisker reinforcement industries in the Far East. Little has been written on Korean endeavors; therefore, a brief visit was made to South Korea to study carbon fiber activities. With the assistance of the Korean Government, one university and two companies were visited. This article contrasts Korean activities with efforts in Japan and elsewhere.

STATUS OF CARBON FIBER

For a number of years Japan has dominated carbon fiber precursors and has produced significant amounts of polyacrylonitrile (PAN) based carbon fiber. Intensive efforts have been made in pitch-based carbon fiber. In 1986 about 30 Japanese organizations or research teams were working on pitch-based carbon fiber.*

There are numerous attractive properties of pitch-based carbon fibers. Ultrahigh modulus carbon fibers produced from mesophase pitch reach higher modulus levels than fibers produced from other precursor materials. Figure 1 shows selected tensile strength and modulus values for representative PAN- and pitch-based carbon fibers.

To gain perspective on the Korean activity let us consider the overall carbon fiber situation. Table 1 is an estimate of current world production capacity based on major suppliers. Tables 2a and 2b show estimated world consumption of PAN-based carbon fibers by country of origin and type of application. Comparing Tables 1 (capacity, 6,980 tons) and 2 (consumption, 5,165 tons) suggests there is currently an excess production capability for PAN-based carbon fiber.

Table 1 is a conservative estimate of production capacity. Recently the top three PAN fiber producers have been expanding their capacities by 30 to 50 percent (Toray, Toho Rayon, and Hercules). Many new grades of high tensile strength, high modulus, or high elongation fibers are being developed. Referring to Table 1, it is interesting to compare the capacities of the Korea Steel Chemical Co. (KOSCO) with numerous European producers. We see that Korean enterprise is on the lower end of the spectrum and for lower grade general-purpose PAN-based fibers.

Since the United States is the major user of advanced fibers, it is useful to look at estimates of future U.S. consumption. Table 3 is an estimate of U.S. demand through the year 2000; carbon fiber utilization is predicted to increase about fivefold. Korean carbon fiber consumption in 1987 was about 300 tons, and the majority of the fiber was supplied by Japanese manufacturers. Korean companies hope to supply a larger share of their own demand and be more competitive in the international marketplace.

*Otani, S., and A. Oya, Keynote Speech, "Status report on pitch-based carbon fiber in Japan," in *Composites '86, Recent Advances in Japan and the United States*, Proceedings of the Third Japan-U.S. Conference on Composite Material, edited by K. Kawata, S. Umekawa, and A. Kobayashi (Japan Society for Composite Materials, Tokyo, 1986), 1-10.

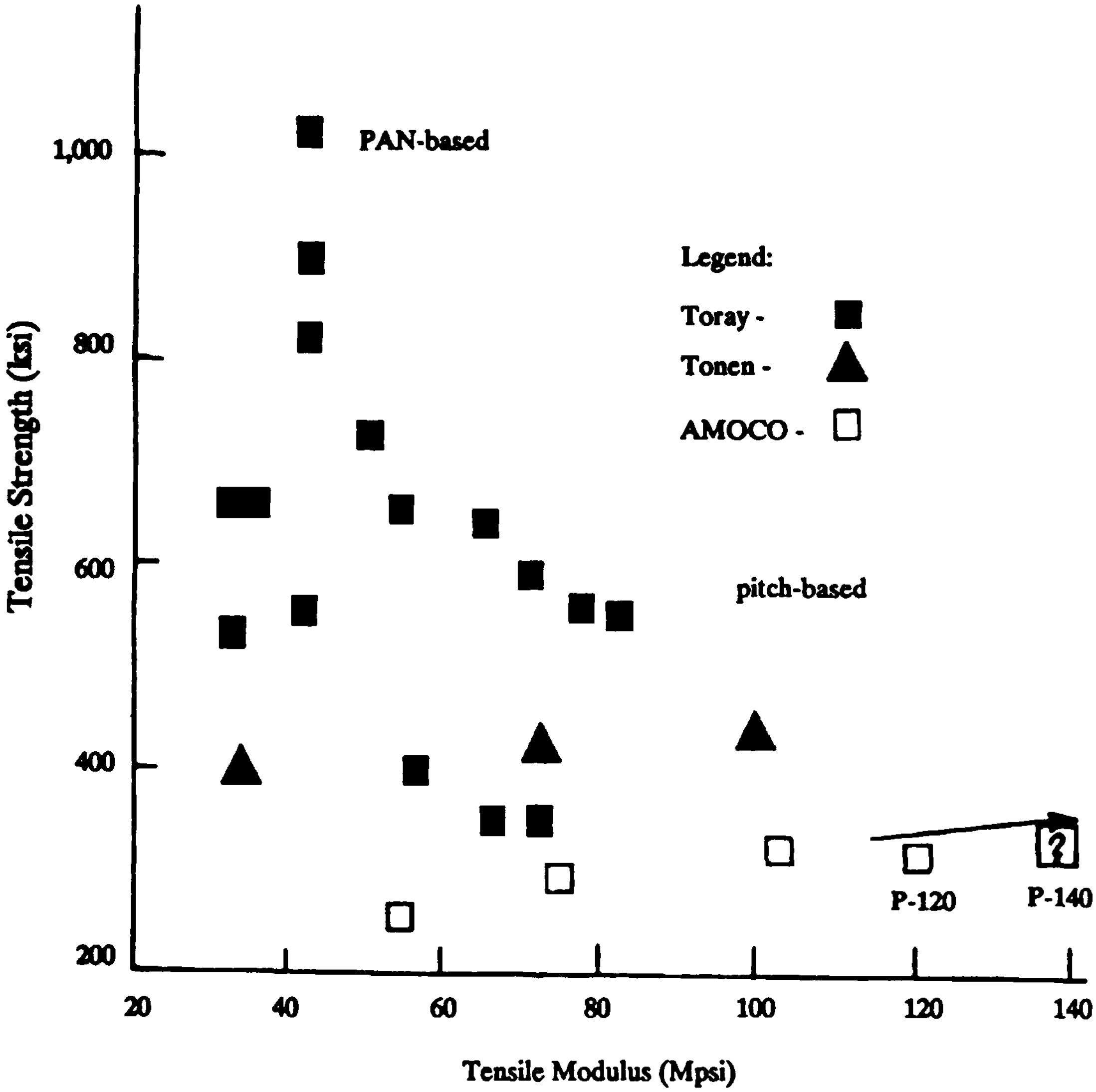


Figure 1. Tensile properties of selected carbon fibers.

KOREAN FIBER DEVELOPMENTS

Korean manufacturers are interested in a wide variety of fibers and have been actively investigating their use. Korea has six major companies concentrating on synthetic fibers and textiles: Cheil Synthetic Textiles, Hanil Synthetic Fibers, Kolon Industries, Samyang, Sunkyong Fibers, and Tongyang Nylon. These companies are concentrating their research on conventional textiles. Korean manufacturers are using a familiar strategy: concentrate investments on high technology and export current, off-the-shelf plant capability and technology. In other words, gradually phase out the lower end of textile technology to developing countries and continually push into leading edge, high performance fiber technologies.

Table 1. Estimated World Production Capacity of Carbon Fibers (Major Suppliers)

[Capacity in tons/yr]

Country	Company	Brand Name	Capacity
PAN-Based Carbon Fibers (from Toray Co. estimates)			
Japan	Toray Industries	Torayca	1,500
	Toho Rayon	Besfight	1,380
	Asahi-Nippon Carbon Fibers	Hi-Carbolon	300
	Mitsubishi Rayon	Pyrofil	120
U.S.A.	Hercules	Magnamite	1,045
	AMOCO Performance Products	Thornel	360
	Celion C.F.	Celion	275
	HITCO	Hi-Tex	125
	Stackpole Carbon	Panex	115
	Great Lakes Carbon	Fortafil	300
	Hysol Grafil	Grafil	150
U.K.	Hysol Grafil	Grafil	150
	R.K. Carbon Fibres	RK Carbon	20
W. Germany	SIGRI	Sigrafil	150
	ENKA	Tenax	350
France	SOFICAL	Filkar	300
Israel	Afikim Carbon Fibers	ACIF	90
Taiwan	Taiwan Plastics	Tairylfil	100
Korea	Korea Steel Chemical Co.	Kosco	150
Total			6,980

(continued)

Table 1. Continued

[Capacity in tons/yr]

Country	Company	Brand Name	Capacity
Pitch-Based Fibers			
U.S.A.	AMOCO Performance Products		250
	Ashland Petroleum	Carboflex	150
Japan[a]	Kureha Chemical	Kureka	1,800
	Dainippon Ink & Chemicals		700
	Mitsubishi Chemical Corp.	Dialead	500
	Nippon Petrochemicals Co., Ltd.		50[b]
	Nippon Oil Co., Ltd.		5[c]
	Nippon Carbon Co., Ltd.		36
	Nitto Boseki Co., Ltd.		20
	Tonen (Toa Nenryo Kogyo)		12
	Kashima Oil Co., Ltd.		12
	Showa Shell Sekiyu K.K.		10
	Shin Nippon Steel		12
	Kobe Steel		5
Total			3,562
R&D, Sample Shipment Stage			
Japan	Koa Oil Co., Ltd		
	Maruzen Petrochemical Co., Ltd.		
	Mitsubishi Petroleum Co., Ltd.		
	Sumitomo Steel		

[a]Continuous and short fibers.
[b]Planned capacity.
[c]Started with 5 tons/yr; 50 tons/yr planned.

The Korea Advanced Institute of Science and Technology (KAIST) and Kolon Industries jointly developed an aramid fiber. Their product at present is identified as a polymer "alloy" and is claimed to have high strength and abrasion resistance. The fiber is quoted as having an elongation of almost 10 percent. KAIST claims that DuPont's Kevlar 979 requires many steps from raw material to fiber, whereas the Korean product is processed more-or-less directly from raw material. Korean industry forecasts a large market for this aramid fiber as a high strength replacement for asbestos, for aerospace applications, in sports and leisure goods, and in various military applications such as ballistic-resistant garments and helmets. U.S. patents have been obtained by the Koreans for this fiber.

Table 2a. Estimated World Consumption of PAN-Based Carbon Fibers (1987-88)

[Amount in tons/yr]

Country	1987		1988	
	Amount	%	Amount	%
U.S.A.	2,500	49	2,900	50
Europe	860	17	990	17
Japan	935	18	970	17
Far East, Others	870	17	1,000	17
Total	5,165	100	5,860	100

Table 2b. Estimated World Consumption of PAN-Based Carbon Fibers According to Application (1987)

[Amount in tons/yr]

Country	Aerospace		Sports		Industrial	
	Amount	%	Amount	%	Amount	%
U.S.A.	1,650	65	350	15	500	20
Europe	485	56	165	19	210	24
Japan	45	5	715	76	175	19
Far East, Others	45	5	695	80	130	15
Total	2,225	43	1,925	38	1,015	19
Total, all categories: 5,165						

Table 3. Estimated U.S. Demand (in tons) for Advanced Fibers

Item	1987	1992	2000	Annual Growth (%) Between--	
				1987/1977	1992/1987
Advanced Fibers	4,846	9,750	23,700	26.5	15.0
Carbon	2,477	5,400	14,265	25.0	16.9
Aramid	2,358	4,335	9,390	29.3	13.0
Boron	7.5	5	4	-7.0	-7.8
Other Fibers	4	10	41	14.9	20.1

Korean manufacturers engaged in or with at least limited involvement in carbon fiber development include: Han Kuk Fiberglass Co., KOSCO, Sunkyong Chemical, Sunkyong Fibers, Lucky Ltd., Pacific Fiber Co., Hanil Synthetic Fiber, Cheil Synthetic Textiles, and Kolon Industries. Emphasis is on PAN-based fibers with laboratory scale efforts on pitch type carbon fibers. They receive strong support from KAIST. At this writing, the specific activities of each organization are not known. Han Kuk Fiberglass Co. was the first in the carbon fiber business in Korea and began producing it in 1982. KOSCO and Sunkyong Chemical both opened new plants in 1986. KOSCO has a plant capacity of 150 tons/yr. Sunkyong began by concentrating on prepregging. Sunkyong Fibers, in cooperation with the Korea Institute of Machinery and Metals, opened a pilot plant for PAN-based carbon fiber in 1984 and a factory in Ulsan for manufacture of carbon fiber prepregs.

CHUNGNAM NATIONAL UNIVERSITY

Chungnam National University, founded in May 1952, has four graduate schools and eight colleges, with 696 faculty members and a student enrollment of over 20,000.

We visited Professor Senung-Kon Ryu, Dept. of Chemical Engineering; Professor Kwan-Hyung Song, Dept. of Naval Architecture and Ocean Engineering; and Dr. Michael Heine, a postdoctoral researcher from the University of Karlsruhle. Heine was a doctoral student of Professor E. Fitzer and is knowledgeable about U.S. research activities in carbon fibers. He was on a 1-month visit to Chungnam National University.

Professor Song's special interest is the use of composites for naval vessels and composite material design approaches. Professor Ryu described the research on carbon fibers and composites. Chungnam University has had a steady stream of foreign students from Japan, Europe, India, and elsewhere. PAN-based carbon fiber studies were conducted from 1983-1986, and pitch-based fiber studies began in 1986. During the PAN fiber phase, about 20 students were engaged in fiber development. Currently there are about 20 students studying fibers and composite materials. The PAN carbon fiber development was funded with United Nations, West German, and Korean support. We were shown the fiber production equipment, which is no longer fully used. It was not a small-scale university research facility but rather a large pilot plant type facility capable of producing tons of material. The equipment was largely of German design. The processing lines were placed in a very compact, vertical arrangement. After several years of effort, the team was able to produce carbon fibers of reasonably high strengths, comparable to T-300 type fiber. The effort was devoted to production technology and the results were transferred to Korean industry. The current pitch-based carbon fiber work is proceeding on a smaller scale, with fibers being produced in kilogram-sized batches.

KOREA STEEL CHEMICAL CO., LTD. (KOSCO)

KOSCO was licensed with R.K. Textile of Great Britain in 1985 for PAN-based carbon fiber production. KOSCO's precursor material is purchased from Courtaulds. KOSCO is also studying carbon fibers based on coal-tar pitch. The company is supporting Dr. Yang-Soo Kim, consultant to KOSCO, and Professor Chang at KAIST. The facility investment in PAN fiber so far has been about $8 or $9 million, not including licensing fees. The furnaces are manufactured in Japan and the production facility is housed in a large (open, not-clean room environment) 20-bay structure, dimensions about 80 by 400 feet. Currently KOSCO has the capacity to creel 216 reels of precursor for their broad goods product. Process control is a four-times-per-shift fiber density measurement and periodic tensile testing of the yarn. However, during a run with a new precursor, gas evolution analyses were performed during carbonizing, graphitizing, and stretching operations. This is not done during routine production. KOSCO was quite open in letting us examine the production facility.

The capacity of this facility is 150 tons/yr, but last year about 130 tons were produced. KOSCO estimates that about 60 percent of the Korean composites product market is supplied by Japan. About 80 percent of that market is for sporting goods. KOSCO is trying to increase a market share that is dominated now by Han Kuk and other Korean firms. Han Kuk produces various fiber-reinforced plastic products. It was not evident that they are producing any carbon fibers in their facilities. KOSCO and others estimate the current Korean market requirement for carbon fiber as 300 tons/yr. KOSCO is trying to develop lower cost fibers, improve interface strength in composites via different sizing methods, and develop new prepreg resin systems and sizing agents. Korean labor costs were only about 2 percent of the fiber costs. About seven people were engaged in production including two technical specialists. This plant is being amortized over a 20-year period. One of the major stumbling blocks is the cost of the precursor, and this is where Japanese firms have an advantage by making their own precursor materials. For this reason most firms are trying to integrate from raw materials to final product. In terms of fiber cost, in 1988 KOSCO carbon fiber was undersold by Japanese competitors. KOSCO sells continuous carbon fiber yarn only in Korea but supplies chopped fiber to the United States.

Currently a typical production run takes about 4 hours. (Production times in some advanced PAN fiber facilities in Japan are about 2 hours!) The process involves 10 minutes exposure of the fiber in the 800 °C zone. According to Kim the main factors in quality control are:

- Precursor quality (moisture percentage and five or six tensile tests per lot)

- Density after oxidation (measured four times per shift)

- Surface treatment (measure coolant flow/min, 10 tests of composite specimens)

- Sizing (needs improved control)

Sizing varies from 0.8 to 1.5 percent by weight, depending on customer requirements.

HAN KUK FIBERGLASS CO., LTD., PUSAN

After trying unsuccessfully for several years to license technology from abroad, Han Kuk developed its own technology. Han Kuk is viewed as the originator of the carbon fiber industry in Korea. Han Kuk began producing carbon prepregs in 1982 and currently has a range of composite products of carbon, glass, Kevlar, and hybrid weaves as well. We were provided a tour of the fiberglass manufacturing plant (U.S. technology) as well as various carbon and glass composite fabrication facilities, but we did not see carbon fiber or carbon fiber prepreg operations. Modest sized autoclave capabilities and a small filament winder were evident. The hand-layup and composite molding operations were reasonably impressive. Han Kuk has molded thick parts and rather complex thin shell monocoque composite structures with unsymmetrical integral bonded stiffeners and odd shapes. A wide variety of secondary and some primary structural parts of glass and carbon-reinforced epoxy and silica phenolic components were observed.

We were led through the carbon tennis racquet production, which relies on hand-layup and a series of process steps using hard (steel) tooling. The critically stressed regions of the racquet had glass fiber inserts and overlays.

Han Kuk is interested in composite products for small truck application and is currently producing composite components for a number of U.S. manufacturers. A number of commercial glass and carbon composite products, of both civilian and military scope, were on display. Various sporting goods, fishing rods, tennis racquets, golf clubs, a collapsible molded composite wheelchair, munitions cases, containers, launch tubes, helmets, canopies, and missile transition sections were shown. An "armor" element, a rather thick (about 4 inches) alumina tile, about 10 by 10 inches and totally encased in a thick layer of fiber-reinforced plastic, was included in the display. It had been ballistically evaluated and appears as if it would serve as a portable armor building block.

CONCLUSIONS

Several Korean organizations are involved in carbon fiber and advanced composite development. Although the current major supplier is producing PAN-based carbon fiber with properties roughly equivalent to the T-300 fiber, it has a program to improve the properties. Korean engineers have a good knowledge of composite applications. Manufacturers have made significant investments and intend to be a supplier of carbon fibers and fiber-based materials. At the present time Korea produces a very small percentage of the PAN-based fibers. A much smaller amount of pitch-based fibers is produced on a laboratory scale. Thus Korea's participation in the carbon fiber market is just beginning and it remains to be seen whether it will be able to be competitive in this business, particularly for high performance fibers.

Edward Mark Lenoe, on leave from the Army Materials and Mechanics Research Center, joined the staff of ONRFE/AFOSRFE/AROFE in October 1985. Previously he managed the AMMRC Reliability Mechanics and Standardization Division, served as operating agent for the International Energy Agency implementing agreements on high temperature ceramics for heat engine applications, and also managed numerous major contracts. He completed a 2-year ONR assignment on structural ceramics. Now he is on an ARO assignment. His studies for ARO are devoted to advanced materials and relevant emerging technologies.

A SERIES OF SITE VISITS ON SUPERCONDUCTIVITY

Donald Liebenberg

This article presents the highlights from a series of site visits to high temperature superconductivity and superconducting electronics research laboratories.

INTERNATIONAL SUPERCONDUCTIVITY TECHNOLOGY CENTER

Professor S. Tanaka, who has retired from the University of Tokyo, is the organizer of the International Superconductivity Technology Center (ISTEC). The laboratory is being refurbished in a Tokyo Gas building near the University of Tokyo. The Japan Fine Ceramics Center (JFCC) at Nagoya has a unit of ISTEC with specific interest in increasing critical current in bulk materials. The research groups of ISTEC are organized as shown in Table 1. The group leaders are all permanent ISTEC staff paid by ISTEC who have a variety of international backgrounds and fluency in English. The total staff beginning April 1989 will be about 100, with support for most group members being provided by their permanent employer/member of ISTEC. The average age of the current staff was noted by Prof. Tanaka to be 30 years.

Primarily the emphasis will be on basic studies, new materials, process development in films, and critical current

Table 1. Research Groups of ISTEC

Group No. 3	Main Activity	Origin of Group Leaders	Staff JF88	Staff JF89
1	Basic Research	Electrotechnical Lab	10	17
2	Oxide Material Preparation	Canada	12	20
3[a]	--	--	--	--
4	Chemical Process	MIT	9	20
5	Physical Process	NHK Lab	10	20
6	Nagoya Critical Current	Max Planck Inst.	6	12

[a]Empty--will be Organic Superconductors.

increase in bulk materials. Prof. Tanaka noted that the processing of wire would not be carried out since that is an individual industrial problem. The material preparation group (group 2) will have a heavy emphasis on new materials. When I asked where he would find the 20 projected first-rate solid state chemists he agreed that would take work. The chemical process group (group 4) will study single-crystal growth, metalorganic chemical vapor deposition (MOCVD), CVD, and chemical processing of thin films. The physical process group (group 5) will carry out the laser melt preparation and do various multilayer studies. Tanaka pointed out that the study of other properties of these interesting materials will be done with groups 1 and 5. Group 6 will respond to a main conclusion of the International Symposium on Superconductivity (ISS '88) that further work is needed to understand pinning and control microstructure. The proximity of this group to JFCC is an indication that excellent ceramics techniques will be used.

Equipment for these labs is being procured and includes such items as a 400-keV transmission electron microscope (TEM) and scanning electron microscope (SEM). Of the initial fee paid by each member company, about one-half will be spent for equipment, about $20M at the current exchange rate.

Funds for ISTEC are provided by member companies and the Government. About 45 full-member companies initially paid ¥100M each ($34M at ¥132/$1). This year companies will pay about $4M and the Government will provide $4M; next year the Government contribution is slated to increase to $8M and will remain at that level for the remainder of the project, which is expected to last 10 years. With the increased Government support the per-staff support level will reach ¥20M ($150K), which Prof. Tanaka stated is the current industrial lab support level in Japan.

There will be opportunities for 15 to 30 students to do thesis research at ISTEC. These students will come from all over Japan, but as to be expected, good relations with the University of Tokyo will continue.

Visitors to ISTEC are encouraged, and Prof. Tanaka discussed some planned visits from scientists from Lancaster, U.K., Los Alamos, U.S., and Kernforschungzentrum Karlsruhe, West Germany, and an MIT student of Prof. Bowen. A visit from an Australian scientists is being negotiated.

Patent regulations for ISTEC are a particularly delicate issue. Currently one-half of any patent generated in ISTEC belongs to the group. Under consideration is how to distribute rights to individuals or visiting organizations, etc. In September 1988 Prof. Tanaka completed a first draft; after reviews, it will be translated into English and more widely discussed. Ultimately a patent policy will emerge. Some complications will result when ISTEC and an outsider (nonmember) provide support to an individual researcher who is part of a patent. At issue is the relation of individuals to patents filed in other countries. I suspect that a satisfactory resolution of this situation could well represent a model for other international cooperative research. We also discussed other projects in Japan. Prof. Tanaka expressed the thought that American pessimism was giving way to optimism.

A magnetically levitated train, which is viewed as a national project, should be ready for public introduction shortly after the year 2000. A new 50-km test track is planned; additional studies to test the effect of passing will require a parallel track, which will be constructed. He believes a budget of \$3B/yr will be committed to this project. The Ministry of Planning is studying the public introduction. Conventional superconductors will be used initially, with the move to the high temperature superconductors occurring as rapidly as possible. Part of this driving interest in the liquid-nitrogen-cooled superconductors is the lack of a basic helium gas resource in Japan and the acute awareness of the dependence on outside sources of helium. Prof. Tanaka noted that a sudden increase in helium use in the United States could curtail supplies to Japan. The proposed rail line would require substantial amounts of helium gas.

Prof. Tanaka noted that in many industrial companies the research pace is about to accelerate. While companies have been building up their staff, new specialized equipment (SEM, controlled furnaces, HIPing, etc.) has been arriving that will be used in this research. So Japan remains optimistic and determined to seek the benefits from high temperature superconductivity.

Prof. Tanaka discussed some research in his group, and Dr. Sumio Ikegawa, of Toshiba but assigned to the Tanaka group*, discussed some studies of the nonlinear effects in the weak link materials. Tanaka's work will be published as part of the Nobel Symposium 1988. Basically the Drude type plasma frequency is related to the transition temperatures of the various stoichiometries in YBCO, BiSCCO, and LSCO so that $T_c \propto \omega^2$. The meaning of n and m* in the Drude equation may be modified, but the fact that this relation is independent of the material suggests the same kind of mechanism of superconductivity in these several high temperature superconductors. The problem is what kind of quasi-particle is formed in these oxide systems. He had not looked at the heavy fermions to see if a similar relation might apply. Dr. Ikegawa has examined the ac-dc conversion in ceramic superconductors and finds that the reverse Josephson effect, as seen by Chen (Wayne State), can be described in terms of a nonlinear interference effect between the phase of the fundamental and second harmonic waves in a system of nonlinear resistance--weak links. That study will be published in the ISTEC proceedings.

JAPAN FINE CERAMICS CENTER

Accompanying Dr. R. Gottschall, Department of Energy, and Dr. G. Eyring, Office of Technology Assessment, I visited with Mr. Kozo Esaki and N. Kosuge of the Japan Fine Ceramics Center (JFCC). Founded in May 1985, the JFCC is in a new building in Nagoya that was completed in April 1987, and they are still receiving equipment and staff. Initial funding was ¥11B, mostly from contributing industries and the Nagoya Government, with about ¥0.5B coming indirectly from the Ministry of International Trade and Industry (MITI). The staff consists of around 60 researchers: 12 with Ph.D. degrees, 12 with M.S. degrees, 18 with B.S. degrees, and the rest technicians. Some two-thirds of this staff are on assignment (an average of 2 years) and are paid directly by their company. The JFCC

*In my notes Prof. Tanaka had discussed his new grant that provided about 11 positions for people from industry to come and train in his laboratory in this area.

sponsors the Nagoya Trade Fair, workshops, seminars, and courses (now twice a year for 3 months for five students). Located in this new building are facilities for ISTEC; although various facilities will be shared, ISTEC is independent. Of the JFCC staff some 10 to 15 percent in FY88 are engaged in high temperature superconductivity research. So far four foreign researchers have arrived, including Ms. N. Tsai from the United States.

The research could not be discussed for proprietary reasons. At the ISTEC symposium work on critical current measurements was reported and samples that were measured were on display in the laboratories. Special equipment for high-pressure hot-isostatic pressing was available to 20,000 kgf, the top-of-the-line 400-keV TEM/SEM system was in operation, and considerable other analytic equipment is described in the Japanese language brochure.

FUJITSU

Dr. Eyring and I were hosted by Dr. T. Mitsugi, board director, and others. Fujitsu, Ltd., the parent company of Fujitsu Laboratories, had $16.4B in sales in 1988, 72 percent of which is in computer-related and communications devices. Fujitsu Labs were established in 1968 and now have 1,400 employees, including 1,020 engineers. The educational levels of the engineers are as follows: 10 percent Ph.D., 48 percent M.S., and 42 percent B.S. The academic disciplines represented include 48 percent electronic engineering, 20 percent physics, and 10 percent each chemistry and computer science. Fujitsu's invention of the high electron mobility transistor (HEMT) and recent work on bipolar and heterojunction devices are especially interesting. At the parent company Si work predominates, while GaAs research is conducted at Fujitsu Labs. The Labs are also conducting research on optical devices including HgCdTe detectors and on Josephson devices.

Three areas of cryogenic technology were discussed: (1) ceramics, including bulk materials and packaging; (2) Josephson junction devices and wiring and integration with semiconductor chips; and (3) crystal growth and evaluation with new work in CVD to enhance critical current values. It will take 10 to 20 years for optoelectronic computing and Josephson technology to be developed into products. A switching, 1-bit circuit has been developed, but the switch is electron (not photon) operated.

Considerable work is being carried out now with Bi-Sr-Ca-Cu-O material rather than YBCO because of its better environmental stability. Substrates of Al_2O_3 and MgO are used for large films and MgO and YSZ are used for small and single-crystal films. A thick film on Al_2O_3 is a problem because of aluminum diffusion during annealing. Values of T_c = 80 K on MgO and YSZ are reported. Fujitsu developed a thermal process of quick firing to 880 °C in about 1 hour, holding 15 minutes, and cooling for 1 hour. The adhesion at the interface makes it difficult to use laser heating that heats the outer surface preferentially. Screen-printed circuit patterns have been made on Al_2O_3 and finished with an 80-K transition temperature. The higher temperature phase is hard to stabilize; thus, lead cannot be used at high annealing temperatures. The exact conditions have been clarified: microstructure has less porosity after 4 hours than after 10 minutes, but the best superconductivity is found at 880 °C for

10 minutes. A clean cross section was shown for such a film on Al_2O_3--a 30-μm-thick film whose interface layer of about 3 μm is not superconducting. The critical current is not large, 100 A/cm². The temperature time (profile optimum) was determined. Fujitsu has also been able to test a multilevel design by laser drilling a 300-μm hole in a 600-μm-thick Al_2O_3 layer, filling with BiSCO powder, printing on the flat surface, and firing to obtain a circuit continuity.

Single-crystal studies were produced in a CVD apparatus with five-zone temperature control and component oxidation only in the substrate chamber. Deposition on a 30- by 30-mm MgO substrate produced a single, large (about 70 percent) region with uniform thickness and mirrorlike surface. This technique is much improved compared to the surface produced in e-beam sputtering. Some holes are observed but otherwise the film surface is very smooth. The x-ray diffraction for a 0.3-meter-thick film shows c-axis = 30.5 Å and for a 0.1-meter-thick film a = 5 Å but b = 27 Å. This verifies a superlattice. The resistance curves give $T_c(0)$ = 78 K and the j_c for a 0.1-μm-thick film is 10^4 A/cm² at 10 K.

A number of techniques were shown to provide a substrate match to silicon. The formation of a spinel, MgO-Al_2O_3, on Si gave a SiO_2 interface during thermal oxidation. A single-crystal spinel is formed; some line defects result from differences in thermal expansion. Also a Si-spinel-MgO (1-μm-thick) film multilayer has been grown. Fujitsu is pursuing this with the BiSCCO films. Fujitsu is not currently working with thallium and is working less with YBCO in favor of the BiSCCO.

Dr. Hasuo gave results similar to his lecture at ISS '88. He described the ongoing work on patterning of YBCO on MgO into nonsuperconducting, semiconducting, and superconducting regions by control of oxygen stoichiometry. In this way a tunnel junction has been patterned; a gap of 12 meV is found that disappears above 50 K in a 0.5-μm-thick YBCO patterned film. The minimum line width with demonstrated superconductivity--a measure I take of progress--was reported to be tens of micrometers. Last year a 320-μm line was the minimum. For electronic devices, Dr. Hasuo believes single crystals must be developed and that processing temperatures of less than 500 °C must be found.

An important study of the environmental sensitivity of the YBCO and BiSCCO was carried out and a plasma polymerization process with CHF_3 was used to make an effective barrier. While the product polymer was determined to be a teflon, the spray application of teflon (less trouble) was not effective as a barrier. The plasma deposition barrier was tested in water, at 150 °C in air, and also in 90 °C water all without change in the T_c of YBCO. Fujitsu's results with an unprotected BiSCO film indicated degradation in water, although a high surface quality film is less affected. The plasma fluorocarbon coating is also effective for the BiSCCO films.

The significant progress on low temperature superconducting electronics still has limitations--a 64-kbit RAM is the largest Dr. Hasuo can foresee and the access time, 590 ps for a 5-μm line technology, will be reduced to ~200 ps for 2-μm line technology but is still larger than semiconductor memory. At present a 1-Mbit RAM cannot be imagined. Power dissipation will limit the usefulness of high temperature superconductors.

The visit to the clean room was most useful. The 10,000 class design clean room was measured as a 1,000 class. The CVD apparatus was shown and further described. Control was to ±1 °C at the 200-°C level and to ±4 °C at the 550-°C level and was monitored by internal thermocouples attached to the boats. Wire radiant heaters were used. The flow gas was helium gas bubbled through water and mixed with oxygen. The Nb facilities for sputtering $Nb/Al_2O_3/Nb$ layers without breaking vacuum even during oxidation of the Al layer were shown. No NbN work is in progress.

A photo resist process is used to pattern. A new "NeWa" rf sputtering system was shown; an older "ULVAC" was also shown. For the BiSCCO material a 40 lead chip limits test patterns to 10 units (for a four-probe measurement). Etching is hard to do. Wet etching is difficult because of poor vertical edge control; dry etching is preferential to the components in BiSCCO. U.S. groups were noted as using argon ion milling, but it is difficult to control the depth by this approach. Work is underway to set up an old molecular beam epitaxy (MBE) machine for the BiSCCO in order to try to accomplish low-substrate, no-postanneal film production. A two-gun e-beam sputter unit was used: one gun for oxygen plasma, the other with multiple targets. The equipment setup was apparently dedicated to either the Nb or Bi activity, frequently no longer used semiconductor equipment or abandoned wider line equipment. But clean room conditions and attention to cleanliness were clearly part of a serious and determined effort--a small indication was the special paper we were provided for notetaking in the clean room.

FUJIKURA

Dr. G. Eyring and I met with Mr. H. Osani, general manager, Tokyo Laboratory, and others. This large cable company has a history since 1965 of cooperation with the Electrotechnical Laboratory (ETL) in superconducting magnet technology. Some notable dates: 1974--hollow tubing NbTi, 1976--multifilament hollow core NbTi, 1978--Nb_3Sn, 1983--magnet of hollow core Nb_3Sn. In 1981, Fujikura fabricated a 1.4-mm-final-diameter wire with 7,735 filaments of Nb_3Sn and nearly complete reaction in each filament; a reduction ratio of 1000 was achieved. A hollow rectangle with four groups of braided and embedded wires is prepared as the final magnet winding cable. A j_c of about 2×10^5 A/cm^2 is achieved at 10 T and 4.2 K. A stabilizer of 60 percent copper metal is used. Fujikura has an in-situ device for making fine wire of CuNb or CuV with provision to externally coat with Sn or Ba. For a bending strain of up to 1 percent in this cable the critical current does not decrease. Fujikura hopes that this cable will be used in the Moonlight project, but apparently the first rotor will be of NbTi cable.

Fujikura's high temperature superconductor research was started promptly after Professor Tanaka's work. The laboratory is located close to Tokyo University. Fujikura is conducting a very ambitious and determined effort to pursue the development of wire for energy use. About two-thirds of the research is now in the oxide materials. The Research and Development (R&D) Department includes the Fine Particle Department, Sensor Applications Department, and Metal Finishing Group. Other groups are listed as advisory. The company is an active participant in MITI projects and ISTEC. Fujikura has cooperative projects with ETL, the National Research Institute for Metals (NRIM), and Tohoku University. The main targets are: high j_c film processes; application of film processes to wire (also to pages); and development of high j_c wire for coil, new high T_c materials, and Nb_3Sn wire and coils for MITI's supergenerator project. Y, Bi, Tl, and other materials will be used in these projects. Fujikura has processed wires of YBCO that exhibit no cracking and have critical current densities of 3,900 A/cm^2 by a solid phase powder, metal sheath, extrusion, reaction, sheath removal, and final annealing. Removal of the silver sheath is important because the differential thermal expansion of silver (greater than oxide) causes cracking during annealing. Random grain orientation in extrusion was obtained. The strain tolerance of this wire is nearly 0 percent. No work with composite materials (Prof. Wu, Alabama BiSCCO + Ag) has been done. A study of the YBCO phase diagram of oxides has provided insight into a new process for the 1,2,3 phase. Y_2BaCuO_5 and Ba-Cu oxides (ratio of Ba:Cu of 3:5) have been used to produce YBCO (1,2,3). This work was discussed at ISS '88. Fujikura used this process at 930 °C for 0.2 hour to obtain a product with a j_c of about 2,000 A/cm^2. A cross-sectional optical micrograph indicated green and black phases. Although the minimum decomposition temperature occurs near this 3:5 ratio and is 926 °C, the actual process temperature to achieve the 1,2,3 phase is 950 °C because of the mixed phase region. A composite process was described and results in a j_c of about 730 A/cm_2 for wire, which is not yet equal to the bulk material. Thallium efforts have begun, but further work awaits the completion of a specially equipped laboratory to use this material. The highest T_c (~118 K) is achieved with 880-°C anneal in the 2223 phase. Fujikura is pursuing the thallium work in the belief that the higher T_c will be important and that the material is easier to stabilize than the higher T_c BiSCCO material.

We viewed the laboratory and were shown a variety of new equipment, such as the CVD apparatus just being installed; the ion beam, three-gun, oxygen-plasma-assisted unit in operation; and the rf magnetron sputtering system. The excimer laser sputtering system is waiting delivery. All the preparation equipment will be in a clean room. A superconductivity test system, made by Chino, was installed for simultaneous ac susceptibility and resistance measurements, conducted automatically with computer-controlled temperature and with data processing. A room temperature to 20 K is achieved with an installed helium gas refrigerator. Indium-ultrasonic soldering has been used for attaching lead, but now silver and gold leads are being investigated. An automatic particle distribution system was installed. Separate equipment for the thallium preparation will be procured. This effort is being undertaken by a large company with both significant resources and a business understanding to make the technology-product transition.

NATIONAL INSTITUTE FOR RESEARCH IN INORGANIC MATERIALS

Together with Drs. G. Eyring and R. Gottschall we met with Dr. Nobuo Setaka, director general of the National Institute for Research in Inorganic Materials (NIRIM). NIRIM was established in

1966 and is an institute within the Science and Technology Agency (STA). It is composed of small, seven- to nine-member teams who propose and carry out research on a topic for a period of about 5 years. Presently 15 groups and 2 research stations (a group around a technique of high temperature and high pressure) are in place and 3 groups are involved in high temperature superconductivity, new materials, structural determination, and single-crystal growth. There are about 30 people with 10 main contributors to the high temperature superconductivity effort here.

A strong concentration on the study of oxygenation in YBCO, LaBCO, and BiSCO has included studies of Nd-doped YBCO where Nd has also been substituted for Ba. The LaBCO and YBCO studies discussed by Dr. Yoshio Ishizawa are most interesting because they show the plateau in YBCO transition temperature versus oxygen deficiency and the LaBCO (1,2,3 structure) steep decrease to $j_c = 0$. New data with Fe, Co, Ni, or Zn show a plateau in the LaBCO (1,2,3) phase at about a 3-percent level of substitution, a tetragonal phase. The current interest is BiSCCO since following the discovery by Dr. Maeda, NIRIM, the NRIM people did the structure determination. No current work is going on in thallium or the Ba-K-Bi-O compound.

As yet the NIRIM people feel that no completely single phase of the high temperature phase BICSSO (110 K) material has been produced. Recent reinterpretation of x-ray diffraction results suggests an incommensurate modulated structure to account for some satellite reflections. Bigger single crystals are desirable for several experiments including neutron diffraction studies for which such crystals have been requested of NIRIM. Dr. Shigeyuki Kimura described the results that have produced 10- by 3- by 0.1-mm crystal plates from a 1/4-inch-diameter "single" crystal boule. These results are interesting since $T_c(0)$ is 92 K between the previously found high and low temperature phases. The nearly tetragonal structure with superstructure has a = 5.43 Å, b = 5.43 Å, and c = 30.63 Å. A float zone method of growth (pioneered for various materials at NIRIM) was used. Some inclusions have been identified in the boule. The anisotropy of the resistivity is under study.

A new high resolution microscope will be constructed at NIRIM, which is already known world wide for the work of Dr. Shigeo Horiuchi. He has found a new lens design by finite element analysis of the focusing magnets and will soon seek bids for the construction of the machine using at least 1.25-MeV electrons. The question of sample change during study at these electron energies will be examined using dynamic recording techniques of the images. A point resolution of 1 Å is expected.

ELECTROTECHNICAL LABORATORY

Drs. R. Gottschall and G. Eyring and I met with Dr. Y. Akiyama, information office director, Electrotechnical Laboratory (ETL). A background video was shown on ETL as a standards laboratory, communications research enterprise, and the current multifaceted research and development laboratory with a staff of 895 including 560 researchers. Superconductivity studies started in 1958 and the helium liquefier was the second to be installed in Japan. At present 50 to 60 people are working in the area of superconductivity. About 30 reprints of publications since 1987 in the area of high temperature superconductivity were presented to us.

Dr. Yoichi Kimura from Advanced Technology discussed wire and materials development. Their work has included NbTi, Nb_3Sn, Nb_3Ge, and chevrel phase as conventional superconductors. The Nb_3Ge is produced by a CVD process as tape and they have made lengths of 100 meters. Powder technology in a molybdenum tube with hot swaging is used to produce chevrel phase materials. A sample has been shown to have an H_{c2} of 27 T, although the critical current is still 100 to 1,000 times less than needed for a magnet to be equivalent to Nb_3Sn. A tantalum tube could be used to increase the j_c but at the loss of flexibility. They are trying to achieve 10^4 A/cm^2 at 18 T.

The Moonlight supergenerator project will provide a test of only the rotor, and ETL expects the first material to be tried will be NbTi. Started during FY88, the project will run 8 years, and Dr. Kimura hopes a subsequent project will develop an armature of superconductors as well. Questions on the outcome of the feasibility study, conducted the preceding 3 years, were referred to the IEA meeting earlier in September where the study was presented.

Dr. Susumu Takada, chief, Cryoelectronics, discussed the voltage standard (a 1-volt system made at ETL), the SQUID sensors, a four-SQUID chip circuit for medical (especially brain) research, and the computer circuitry that is in the final stages of a several-year supercomputer alternative technologies project. An NMR microscope was displayed in a video, one of two we viewed. The high temperature superconductivity studies are directed to electronic device use; they are working only with YBCO since the studies are funded at a low level from discretionary funds, though a new project to start next year will likely include their efforts. The value of T_c is not so important as to achieve a good surface so that multilayer structures can be made. Good surface quality films are judged by their ability to give a Fraunhofer-type magnetic field dependence and a YBCO/Au/Nb junction is made with a $T_c \sim 60$ K. This structure was built on an $SrTiO_3$ substrate; the crystallites have random orientation since the YBCO anneal temperature was low (700 °C). They help produce a smooth surface. Wet etching has been done with no further decrease of the 60-K transition temperature. Annealing is done both before and after patterning. The grain size obtained is several hundred Angstroms. The junction made was large in area but they hope to reduce the area. The Au film forms an SNS junction with a thickness of 100 Å, or greater than the YBCO coherence length, and they realize there is some discussion about the interpretation of results.

The penetration depth can be determined, 1.3 μm for this 60-K transition temperature material. A microwave study is being initiated. They are seeking a large energy gap material for electronics use. They will also work on contacts; keeping the oxygen content at a high level to reduce contact resistance is the goal. Tests have been carried out to bond low and high temperature superconductors. A reorganization is planned to enhance the fundamental science area of ETL, and a new building will be built for the study of superconductivity. The superconductivity program will have four parts: (1) understanding physical phenomena, (2) new materials, (3) electronic applications, and (4) power applications. Six theorists form part of the group in superconductivity at ETL.

Organic superconductivity was discussed briefly; whether the University of Tokyo material discussed at ISS '88 was being studied was not clear.

There are opportunities for visiting scientists and they were proud that a significant number of foreign researchers have come for extended times and even more for shorter visits. They are encouraging more American participation.

A quick view from outside the room was provided of facilities for producing the $Nb/Al_2O_3/Nb$ Josephson junctions. The clean room used is a 10,000 class. Both Nb and NbN can be fabricated with the same mask set, depending on the particular investigator. Accomplishments of niobium superconducting electronics were noted: NbN memory 1982, logic gates 1983, ROM and 4-bit LSI system 1984, and a 1-kbit RAM in 1985. Rather than a Henkel design cell size of 100 by 100 μm a cell size of 60 by 30 μm is obtained with a variation in architecture. For the RAM the access time is 350 ps. In 1987 a new Arithmetic Logic Unit was designed, a 2-bit Josephson junction.

ETL maintains very considerable capabilities and the high temperature superconductivity activity is envisioned for the long term with more stable funding, adequate new space, and an increasing staff all part of the plan.

NATIONAL RESEARCH INSTITUTE FOR METALS

With Dr. G. Eyring I visited Dr. Kazamasa Togano at the National Research Institute for Metals (NRIM). Dr. Tachikawa, the previous director, has retired to Tokai University and Dr. Maeda, whose recent discovery of the BiSCCO superconductor opened a new avenue, was away on travel. Dr. Togano, leader of one subgroup in the area of superconducting and cryogenic materials, discussed NRIM's effort in high and low temperature superconductors. Two of the four divisions in Tsukuba are working in superconductivity, and 80 percent of the work is in high temperature superconductivity. About 20 to 30 people of a staff of 70 are involved in Tsukuba. These groups are:

- Surface and Interface Division--the goal is devices. An MBE machine is available and x-ray, TEM structural analysis is done.

- First Research Group (Superconducting Materials)

  (1) Deposition of Y and Bi materials (thallium deposition at Sanyo Electric by cooperation). Mostly physical deposition techniques--sputtering. The goal is to produce a good conductor.

  (2) Fabrication of wire and tape by other methods such as powder or a liquid quench.

  (3) Evaluation including critical current measurements.

  (4) The remaining effort on conventional conductors primarily Nb_3Al.

  (5) Magnetic and materials for refrigeration such as Gd.

  (6) Cryogenic structural materials.

Personnel in these groups are augmented by young people assigned for training by various companies: subgroup 2 has one person each from Sanyo, Asahi, and Furukawa, and subgroup 3 has about seven from Mitsubishi.

Papers published on two recent activities dealt with lead-stabilized Bi-Sr-Ca-Cu-O that gives a $T_c(0) = 110$ K and in bulk a $j_c = 1{,}100$ A/cm^2 at 77 K and 0 T. Higher values were reported for a thallium sample. A powder preparation method was used.

A sheathed Ag/YBCO wire has been drawn from 10 mm to 0.5 mm and has a measured $j_c = 1{,}000$ A/cm^2, which they noted was not quite as good as Sumitomo Electric, who achieved 4,000 A/cm^2 in a sheathed wire.

The equipment at NRIM has kept pace with new activities in high temperature superconductivity. Some equipment, such as the 13-T hybrid NbTi V_3Ga superconducting magnet that has a 3.0-cm-diameter bore and a solenoid length of 12 cm, was planned in advance of their shift of emphasis. Although, with a temperature-controlled insert this equipment has made critical field measurements to higher fields needed for high temperature superconductors and with a filamentary V_3Ga winding can be charged to 13 T in 10 minutes. The large magnet that has a tape V_3Ga and Nb_3Sn and NbTi magnets reaches 18 T with superconducting magnets only. A NELVA rf magnetron sputtering unit, a NELVA EVD-1501 system with a single e-beam gun and one resistance heater, is used for BiSCCO films that are prepared with CaF, SrF, and Bi metal with a postanneal in air or oxygen.

A scanning Auger with 25-nm beam size and 0.3-percent control of energy deposition and an ESCA machine with 0.4-eV energy resolution (said to be the best in the world) and a target area of 200 μm were part of the new equipment in the new building that has been occupied since I was at NRIM 1 year ago. Other sputter systems, one with a rf gun and two dc guns, and two single gun chambers, were installed. The ESCA permits study of the electronic structure near the Fermi surface. This equipment is indicative of substantial commitment to the long-term development for wire and films of the high temperature superconductors.

NTT

Dr. G. Eyring and I were greeted at NTT by Dr. Kiroshi Iwasaki, associate vice president of the Optoelectronics Laboratories. The optoelectronics group is at Ibaraki with about 120 people of which 18 are working on high temperature superconductivity. At present they are not working on organic superconductors, although they are working on organic opto-nonlinear materials. Other groups also work on high temperature superconductivity, such as the LSI group at Atsugi, where the emphasis is on e-beam produced devices. Their earlier work on lead-based technology was stopped shortly after the IBM decision. The basic work on Nb technology was done at Ibaraki, but most of this work has been stopped in favor of the high temperature superconductors. The main effort is directed to a demonstration of the required properties for devices, better films, and new materials. With rf sputtering a critical current of

10^6 A/cm^2 at 77 K has been achieved for a deposited YBCO film. Ion beam evaporation is used to produce 15-mm-diameter films on $SrTiO_3$ (which they make). We viewed the sputtering systems, the ion beam evaporator (new), a Perkin-Elmer Auger spectrometer, substrate cleaning equipment, and photo lithography apparatus. This equipment was located in a class 10,000 clean room. Single crystals are grown by a CuO flux method, 5 cm for LaBaCuO and 2 to 4 mm for YBCO. Only the lower (85-K) temperature phase of the BiSSCO single crystals has been grown.

Dr. Suzuki discussed the work on $BaPbBiO_3$ material that is probably the best in the world. They have used this low carrier density material that is relatively transparent to provide effective coupling between incident photons and a change in the density Cooper pairs via created quasiparticles. The carrier density is 2 x 10^{24} and the coherence length is 140 Å.

NTT was the first to produce sputtered films of the La material and to study the anisotropy by using various surfaces of substrate strontium titanate to control c-axis orientation. The [100] surface was used for c perpendicular to surface and the [110] surface for either c parallel or sometimes at 45° out of the surface. Twinning may or may not be produced. The 214 phase of $LaSrCuO_4$ is produced. The small 1,2,3 YBCO single crystals are fitted with 50-μm square gold pads by evaporation and leads are applied with a silver paste that is dried at 400 °C. BISCCO single crystals have been made. A SQUID of about 5 μm was made of YBCO but the Josephson junction is across grain boundaries. At 4.2 K in an applied 6-GHz microwave radiation the Josephson steps are very sharp to high order. But a magnetic field modulation does not display much evidence of coherency. The difference seems intriguing. The junction had a length of 20 μm and the grain size was 0.5 μm, so there were many boundaries in the junction for the flux creep processes. They have made some multilayers of MgO/YBCO/Al_2O_3/Pb or Nb; at present only a small critical current is obtained. The smallest line width for which superconductivity is observed in the YBCO is 2 μm; for a 1-μm line no superconductivity was found. Their efforts are directed to basic studies, improved critical current, and high quality surfaces, and they are just setting up to make noise measurements. They noted that a microwave detector was a likely first application but stressed that knowledge of the carrier density needs to be better determined as well as other physical properties before application possibilities can be more fully assessed.

Their equipment is consistent with this view. An Oxford magnet of new design to reach 12 T is installed for critical field measurements. A Quantum Design susceptometer is one of 10 in Japan. Resistance can be determined more or less automatically.

Thermoelectric power measurements are available, and Hall effect is measured. Optical properties, reflectivity and, with a newly installed system, Raman spectra can be measured. They noted the availability of three EG&G (PAR) digital lock-in amplifiers that work to 500 kHz and are a new product. Two of them were visible in the lab. A pressure clamp to 20 kbar was in use on an automatic temperature-controlled cryogenic system, now measuring the high pressure resistivity curve of

YBCO; they will do BiSCCO. While the personnel are not expanding, the new equipment enhances their productivity greatly.

HITACHI CENTRAL RESEARCH LABORATORY

Dr. G. Eyring and I visited with Dr. Ushio Kawabe, chief researcher at Hitachi in the superconductivity area. The latest annual report shows the continuing commitment to R&D expenditures is $2B or 9.9 percent of total sales ($22.5B). Of 76,000 employees 12,000 are in R&D (does this indicate significant manufacturing automation?), and of these one-third are related to the corporate labs and two-thirds to the business groups where product improvement is carried out. A new corporate Advanced Research Laboratory has just been formed with 60 people and includes very fundamental quantum studies of the Aharonov-Bohm effect--their paper has recently been published. In 1990 this laboratory will move to a site north of Tokyo. At the Central Research Laboratory about 970 people are in 10 departments plus an optoelectronics laboratory, development (includes machine shops), and administration. About 60 people are working on superconductivity, with 30 at the Central Lab. They actively encourage visiting researchers, both professional and postdoctoral, and have about 10 Americans throughout the company. One program is called HIVIPS (Hitachi Visiting Research Program) and has a third category for graduate students.

In superconductivity the main functional relations to be developed for good films are T_c = f (substrate composition, oxygenation, temperature of substrate, cooling profile) and j_c = f (Cu-O layers, oxygenation, film stress, microstructure). They are studying film morphology and the intrinsic properties of anisotropy, sensitivity to oxygenation, etc., which they hope to be able to use in a positive way for devices. Noise properties are being studied, but at present Prof. J. Clarke's measurements that suggest the high temperature superconductor SQUID is 1,000 times noisier are being used. Their own SQUID results did not appear this way; they suggested they were somewhat noisier. To deal with the several current problems they identify needs:

1. Thermal noise $\gamma = I_c\phi_o/kT$.	need high j_c
2. Meissner magnetic fluctuations.	need high H_c
3. Aslamanov-Larkin fluctuations near T_c.	need $T/T_c \leq 1$ or high T_c
4. Josephson junction network phase fluctuations.	need a single crystal (no grain boundaries)

They suggested the future to look as the graph in Figure 1.

When asked how the GaAs development would fit on this graph, it was noted that GaAs "escapes" from this graph because of the use in optoelectronics. The general view is that power limitations of conventional semiconductors in denser configurations will require new technology such as CMOS-dielectric-Josephson junction development.

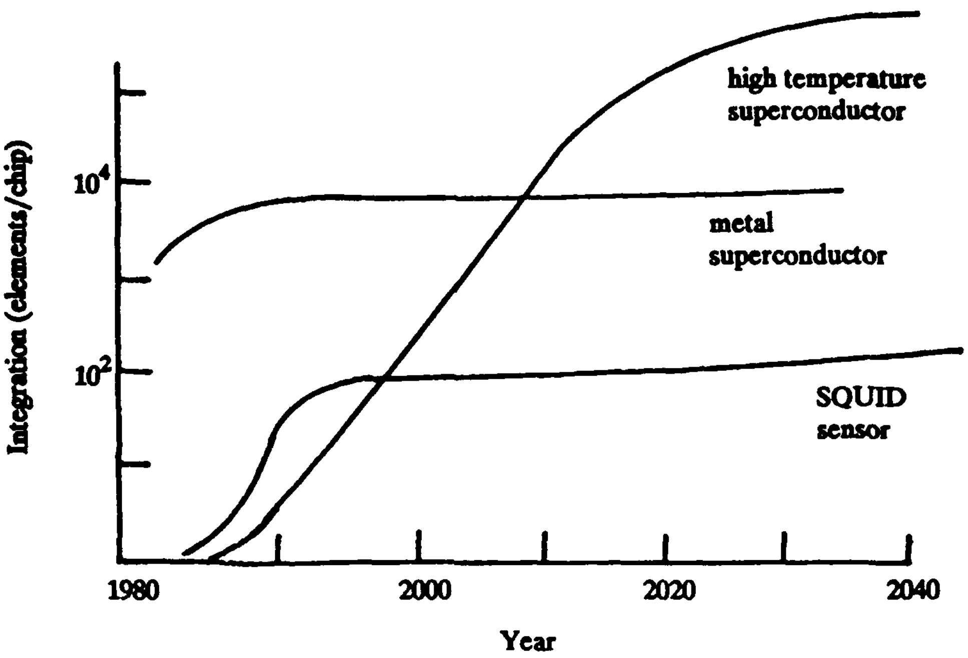


Figure 1. Projected trends in superconductivity for integrated circuits.

Dr. Takeda had presented the status of the superconducting transistor at ISS '88--basically they have yet to get power gain but will continue on this very important problem. Their conventional superconducting circuitry with Nb and NbN has produced a niobium Josephson junction SQUID with 1- to 5-μm square area and a 3,000-A/cm^2 critical current. Using 1.5 micron technology a "3 k gate" board (9 by 10 mm) was fabricated that contains 22,000 junctions. A microprocessor with a 1-kbit RAM is being produced.

Their work on YBCO to produce a SQUID was shown. The coupling coil, also YBCO, has been written as an overlayer so higher temperature operation is possible. A multilayer film set, substrate/YBCO/Au/MgO/YBCO-Nb, is produced, in this case with a dry etching process, and they are able to maintain the oxygen stoichiometry for the superconducting phase. A sharp I-V curve was obtained at 4.2 K, which was less sharp at 69 K, and at 75 K the characteristics were said to be unusable. A very well defined sinusoidal operation was obtained at 65 K with a maximum amplitude of about 1 V and an estimated S/N ~ 10; metal SQUIDs at 4 K show a greater amplitude (10 times). The stress in the YBCO junctions has been reduced by the design geometry.

We toured some laboratories--the Josephson junction picosecond test facility for conventional superconductors, a microwave system, and resistance and susceptibility equipment. One clean room area for Nb circuits was shared with a silicon group. A helium refrigerator with a J-T valve and aluminum heat exchangers has a 4-watt capacity at 4 to 5 K (operating above 1 atm) and had an equipment volume of ~250 ft^3. It had been designed and built within Hitachi.

Hitachi is also very interested in making the superconducting magnets for the next MAGLEV trains. They built the cars for the present tests and they supply the Shinkansen trains. Their view of superconductivity and of the high temperature materials seems very optimistic and they are expanding their efforts in this area. While our visit was far too short to see very much detail there is no doubt about their dedication and the substantial gains they have already made.

U.S. EMBASSY LIST OF SCIENCE REPORTS

This is a listing of U.S. Embassy Science Reports. Some of these are STRIDE Reports; however, this list is inclusive. STRIDE (S&T Reporting and Information Dissemination Enhancement) was developed by the National Science Foundation, Department of State, and the National Technical Information Service in partial response to a requirement of Presidential Executive Order 1259.

Subject	Title	Cable #	Date
AEROSPACE	STOL AIRCRAFT	6689	89/04/14
BIOTECH	INTL. BIOTECH COMPETITION	27218	88/12/16
BIOTECH	JAPAN'S FERMENTATION LABORATORY	21360	88/11/17
BIOTECH	JAPAN'S GENOME MAPPING PROJECT	21144	88/11/14
BIOTECH	MITI INITIATIVE	6689	89/04/14
BIOTECH	MITI WATER TREATMENT PROJ	27041	88/12/15
BIOTECH	RIKEN LIFE SCI. CENTER	03953	89/03/06
CERAMICS	CERAMICS TURBINE PROJECT	02708	89/02/14
COMPUTER	SOFTWARE: MOLECULAR MODEL	8152	89/05/10
ELECTRON	NTT SYNCHROTRON	6689	89/04/14
ELECTRON	RIKEN: X-RAY LASER	6689	89/04/14
ELECTRON	TOSHIBA EPROM	6689	89/04/14
ELECTRON	SOR TECHNOLOGY	8152	89/05/10
ENERGY	REPLICATION OF FUSION TECHNOLOGY	6164	89/04/07
ENERGY	STA SOR PROJECT	27657	88/12/24
ENVIRONMENT	CFC SUBSTITUTES	03285	89/02/23
ENVIRONMENT	CLIMATE CHANGE CONF.	22383	88/12/05
ENVIRONMENT	GLOBAL ENVIRONMENTAL LAB	8152	89/05/10
ENVIRONMENT	HAZARDOUS WASTE	04122	89/03/07
ENVIRONMENT	OZONE PROTOCOL RATIFICATION	18271	88/09/30
ENVIRONMENT	SUBSTITUTE CFC'S	6689	89/04/14
HEALTH	HHS COST SURVEY	00682	89/01/13
NEWMAT	CERAMIC CATALYST	8152	89/05/10
POLICY	AIDS	27725	88/12/27
POLICY	ARCTIC RESEARCH	8152	89/05/10
POLICY	GREY LITERATURE TASKFORCE	21778	88/11/25
POLICY	HFSP	21400	88/11/18
POLICY	HFSP: GOVT PLAN FOR FISCAL 89	8153	89/05/10
POLICY	HFSP: GOVT PLANS NEXT STEPS	7175	89/04/21
POLICY	HUMAN FRONTIER SCIENCE PROG GOVT RESP TO U.S. COMMENTS	6459	89/04/12
POLICY	JAPAN S&T INFO.	02644	89/02/13
POLICY	PICES (PAC INT COUNCIL EXP SEA)	26858	88/12/12
POLICY	PICES	22542	88/12/07
POLICY	PICES	00436	89/01/11
POLICY	RCAST: RES. CENTER FOR ADVANCED S&T	21309	88/11/16
POLICY	STA FELLOWSHIP PROGRAM	22066	88/11/29
POLICY	UJST: JOINT HI-LEVEL PANE	01245	89/01/24
ROBOTICS	SPACE CONSTRUCTION ROBOTS	8152	89/05/10

Subject	Title	Cable #	Date
SPACE	H-1 LAUNCH	17757	88/09/22
SPACE	H-2 ROCKET PROBLEMS	8152	89/05/10
SPACE	SPACE STATION FUNDING	01842	89/02/01
SUPERCOND	FUJITSU JOSEPHSON JUNC	6689	89/04/14
SUPERCOND	HITACHI JOSEPHSON JUNC	6689	89/04/14
SUPERCOND	MAGNETIC LEVITATION TRAIN	6689	89/04/14
SUPERCOND	NRIM TAPE	6689	89/04/14
SUPERCOND	SONY CERAMIC	6689	89/04/14
SUPERCOND	UPDATE ON ISTEC	21310	88/11/16

LIST OF NATIONAL SCIENCE FOUNDATION/TOKYO REPORT MEMORANDA

These report memoranda deal with ongoing work or developments in Japanese science and engineering and with Japanese policy for research in science and engineering, primarily for basic research.

RM#	Date	Title
173	03/09/89	"Requested" Science and Technology Budget of Japanese Government for JFY 1989
172	03/09/89	JFY 1988 R&D Budget of Japan's Ministry of International Trade and Industry (MITI)
171	01/11/89	1988 Survey of Research and Development in Japan
170	12/14/88	General Outline of Government Science and Technology Budget of Japan Fiscal Year 1988
169	12/14/88	R&D Budget of Science and Technology Agency (STA) for JFY 1988
168	12/14/88	MONBUSHO's R&D Budget for JFY 1988
167	12/12/88	MITI: White paper: Trends and Future Tasks In Industrial Technology (Sangyo Gijutsu no Doko to Kadai)
166	10/26/88	Groundbased Astronomy in Japan
165	10/11/88	Monbusho's "Priority Research Area" Grants: 19 New Areas
164	09/27/88	FY1988 Awardees of Monbusho's Grants for "Specially Promoted Distinguished Research" (SPDR)
163	08/26/88	Corporate Superconductivity Research and Development in Japan 1987-1988: A Survey Report
162	08/10/88	STA to Build a High Field Magnet Center for the "Multicore Project"
161	08/01/88	Japan Key Technology Center is Ready to Receive R&D Proposals for Its Capital Investment and Loan Support

RM#	Date	Title
160	07/08/88	Nippon Telephone and Telegraph (NTT) Corporation Laboratories
159	07/08/88	Hitachi Systems Development Laboratory (SDL)
158	07/08/88	Japanese Government R&D Programs with Industry: MITI and Ministry of Education
157	06/24/88	Japanese Fellowships for International Exchanges of Young Scientists and Engineers
156	06/16/88	Sharp Corporation Engineering Center
155	05/13/88	International Superconductivity Technology Center (ISTEC)
154	05/13/88	Matsushita Research Institute Tokyo, Inc. (MRIT)
153	04/18/88	Hitachi Production Engineering Research Laboratory (PERL)
152	04/18/88	Japanese Government and Corporate Funding for Superconductivity R&D
151	04/14/88	MITI's FY'88 Budget for Superconductivity R&D
150	04/06/88	International Superconductivity Technology Center Commemorative Symposium - March 28, 1988
149	03/25/88	MITI to Reorganize NEDO into the New Energy and Industrial Technology R&D Organization (Shin Enerugi Sangyo Gijutsu Sogo Kaihatsu Kiko)
148	02/09/88	SIGMA Project (The Software Generator and Maintenance Aids Project)
147	02/05/88	The Japanese Government's "Requested" Science and Technology Budget - JFY 1988
146	01/20/88	STA's New Initiative for Research Cooperation
145	01/05/88	1987 Survey of Research and Development in Japan

RM#	Date	Title
144	12/30/87	Japan's FY 1987 Science and Technology Budget General Outline
143	12/21/87	Bio-oriented Technology Research Advancement Institution (BRAIN)
142	12/18/87	Exploratory Research for Advanced Technology (ERATO) - Summary of Current Projects
141	12/18/87	Japanese Companies Received 360 Foreign Researchers in 1986 - Summary of a Survey by STA
140	09/30/87	Impressions of High Tc Superconductivity in Japan
139	09/24/87	Visit with Professor Yoshio Muto, Senior Superconductivity Specialist
138	09/16/87	Report on an American Visiting Group's Impressions of High Tc Superconductivity in Japan
137	09/09/87	The 18th International Conference on Low Temperature Physics (LT-18)
136	09/21/87	FY 1987 Awardees of Monbusho's Grants for "Specially Promoted Distinguished Research" (SPDR - Tokubetsu Suishin Kenkyu)
135	08/28/87	Human Gene Analysis Efforts Supported by Science and Technology Agency of Japan
134	08/18/87	Science and Technology Agency Proposes to Promote R&D in Government Laboratories through Collaboration of Scientists from Different Organizations including Those from Foreign Countries
133	08/17/87	Monbusho's R&D Budget for JFY 1987
132	08/17/87	Japan's Ministry of International Trade and Industry (MITI) - R&D Budget for JFY 1987
131	08/17/87	Monbusho Plans to Establish Foreign Post-Doctoral Fellowship Program

RM#	Date	Title
130	08/10/87	Japan Key Technology Center is Ready to Receive R&D Proposals for Its Capital Investment and Loan Support
129	07/30/87	Science and Technology Agency to Propose New Initiative for R&D on New Superconductive Materials
128	07/23/87	Supercomputers in Japan
127	06/30/87	Japan's Science and Technology Agency (STA) R&D Budget for JFY 1987
126	06/09/87	Aseismic Base Isolation

INTERNATIONAL MEETINGS IN THE FAR EAST
1989-1994

Compiled by Yuko Ushino

The Japan Convention Bureau, the Science Council of Japan, and journals of professional societies are the primary sources for this list. Readers are asked to notify us of any upcoming international meetings and exhibitions in the Far East which have not yet been included in this report.

1989

Date	Title/Attendance*	Site	Contact for Information
June 28-July 2	Korea International Welding Show '89	Seoul, Korea	Korea Welding Cooperative Shingsong Building No. 510 24-4 Yoido-dong Youngdungpo-ku, Seoul, Korea
July 2-7	The 27th International Conference on Coordination Chemistry	Gold Coast, Australia	UniQuest Limited University of Queensland St. Lucia, Queensland 4067
July 2-7	XXVII International Conference on Coordination Chemistry	Brisbane, Australia	Professor Clifford J. Hawkins Department of Chemistry University of Queensland Saint Lucia, Brisbane, Queensland 4067
July 3-5	1989 International Micro Process Conference (Micro Process '89)	Kobe, Japan	Secretariat c/o Business Center for Academic Societies Japan Conference Department 3-23-1 Hongo Bunkyo-ku, Tokyo 113
July 3-7	ICOMAT '89: The 6th International Conference for Martensitic Transformations	Sydney, Australia	ICOMAT '89 c/o N.F. Kennon Department of Metallurgy and Materials Engineering University of Wollongong P.O. Box 1144 Wollongong, NSW 2500, Australia
July 3-7	The 4th Japan-China-U.S.A. Symposium on Catalysis	Sapporo, Japan	Professor Masaru Ichikawa, Secretary Research Institute for Catalysis Hokkaido University Kita 11-jo, Nishi 10-chome Kita-ku, Sapporo 060
July 5-8	International Conference on Opto-Electronics Science and Engineering (ICOESE)	Beijing, People's Republic of China	Professor Sun Peimao Department of Precision Instruments Tsinghua University Beijing 100084

*Note: Data format was taken from the Japan International Congress Calendar published by the Japan Convention Bureau.

No. of participating countries
F: No. of overseas participants
J: No. of Japanese participants

1989			
Date	**Title/Attendance**	**Site**	**Contact for Information**
July 6-8	International Conference on Circuits and Systems (ICCAS '89)	Nangjing, People's Republic of China	Professor Wai-Kai Chen Department of Electrical Engineering and Computer Science University of Illinois at Chicago P.O. Box 4348 Chicago, IL 60680
July 7-11	The 11th International Conference on Magnetically Levitated Systems and Linear Drives (Maglev '89)	Yokohama, Japan	Professor E. Masada, Chairman Program Committee of Maglev '89 Department of Electrical Engineering University of Tokyo 7-3-1 Hongo Bunkyo-ku, Tokyo 113
July 8-12	The 2nd Congress of Asian Federation of Societies for Ultrasound in Medicine and Biology	Denpasar, Indonesia	Dr. W.S. Wibisono Cipinang Elok AB-18 Jakarta 13420, Indonesia
July 9-14	The 4th International Conference on Scanning Tunneling Microscopy/ Spectroscopy (ICSTM/STS)	Oharai, Japan	Professor Osamu Faculty of Science Tokyo Institute of Technology 2-12-1 Ohokayama Meguro-ku, Tokyo 152
July 10-14	The 5th World Conference on Transport Research (WCTR)	Yokohama, Japan	The Secretariat Office of '89 WCTR Yokohama c/o Bureau of Urban Planning City of Yokohama 1-1 Minato-cho Naka-ku, Yokohama 231
July 10-14	The 4th International Symposium of Plant Biosystematics (IOPB) 30-F80-J200	Kyoto, Japan	IOPB Symposium c/o Department of Botany Faculty of Science, Kyoto University Kitashirakawa Oiwake-cho Sakyo-ku, Kyoto 606
July 10-14	The 5th World Conference on Transport Research (WCTR)	Yokohama, Japan	Professor E. Masada, Chairman Program Committee of WCTR Department of Electrical Engineering University of Tokyo 7-3-1 Hongo Bunkyo-ku, Tokyo 113
July 10-17	The 8th International Congress of Proto-Zoology	Tsukuba, Japan	Y. Nozawa Department of Biochemistry Gifu University 40 Tsukasamachi Gifu 500
July 11-12	The 8th Kobe International Symposium on Electronics and Information Sciences - Applied Signal Processing	Kobe, Japan	Professor Kotaro Hirano Faculty of Engineering Kobe University Rokko, Nada, Kobe 657
July 11-14	The 1st China-Japan International Symposium on Instrumentation, Measurement and Automatic Control	Beijing, People's Republic of China	Professor Huang Jun-Qin Department of Automatic Control Beijing University of Aeronautics and Astronautics Beijing 100083
July 12-14	Topical Meeting on Solid State Lasers	Beijing, People's Republic of China	Professor Ye Peida University of Beijing Post and Telecommunications Beijing

1989			
Date	**Title/Attendance**	**Site**	**Contact for Information**
July 17-20	The 8th International Conference on Alkali-Aggregate Reaction (8th ICAAR)	Kyoto, Japan	Dr. Toyoaki Miyagawa 8th ICAAR The Society of Materials Science, Japan 1-101 Yoshida Izumidono-cho Sakyo-ku, Kyoto 606
July 17-20	The 9th International Conference on Internal Friction and Ultrasonic Attenuation in Solids (ICIFUAS 9)	Beijing, People's Republic of China	Professor T.S. Ke Laboratory of Internal Friction and Defects in Solids Institute of Solid State Physics Academia Sinica Hefei
July 17-20	Singapore International Conference on Networks: Networking - A Key to Future Communications	Singapore	IEEE Singapore Section, Computer Chapter c/o Times Conferences 19 Tanglin Road 12-02, Tanglin Shopping Center Singapore 1024, Singapore
July 17-21	The 11th International Symposium on Automatic Control in Aerospace	Tsukuba, Japan	Professor Toru Tanabe Department of Aeronautics Faculty of Engineering University of Tokyo 7-3-1 Hongo Bunkyo-ku, Tokyo 113
July 18-21	The 7th International Conference on Integrated Optics and Optical Fiber Communication (IOOC '89)	Kobe, Japan	7th International Conference on Integrated Optics and Optical Fiber Communication (IOOC '89) c/o Business Center for Academic Societies Japan 3-23-1 Hongo Bunkyo-ku, Tokyo 113
July 24-25	International Symposium on Radiation Resistance of Organic Material in Radiation Environment	Takasaki, Japan	Naoyuki Tamura JAERI Takasaki Research Establishment Watanuki-machi Takasaki, Gunma-ken
July 24-26	The 2nd Microoptics Conference/The 9th Topical Meeting on Gradient-Index Imaging Systems (MOC/GRIN '89)	Tokyo, Japan	Mr. Yasuhiko Noguchi Secretariat: MOC/GRIN '89 Banda Building 1-35-5 Yoyogi Shibuya-ku, Tokyo 151
July 27-29	International Conference on Accretion of Discs and Jets in Astrophysics (IUPAP)	Wuhan, People's Republic of China	Professor Yang Lan-Tian Physics Department Hauzhong Normal University Wuhan, Hubei, China
July 31-August 4	The 2nd International Symposium on Plasticity and Its Current Applications 20-F70-J70	Tsu, Mie, Japan	Professor Masataka Tokuda Faculty of Engineering Mie University 1515 Kamihama-cho Tsu, Mie 514
August 1-4	The 7th International Conference on Composite Materials	Beijing, People's Republic of China	Mr. Tu Dezhang Vice Secretary-General Chinese Society of Aeronautics No. 67, South St. Jiao Dao Kou, Beijing 100712, China
August 11-13	International Conference on Constitutive Laws for Engineering Materials	Chongquing, People's Republic of China	Associate Professor Fang Tiantong Department of Engineering Mechanics Chongquing

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Date	**Title/Attendance**	**Site**	**Contact for Information**
August 13-18	Solar Energy Congress Tokyo 1989 40-F600-J400	Tokyo, Japan	Japanese Section of International Solar Energy Society 322 San Patio 3-1-5 Takada-no-baba Shinjuku-ku, Tokyo 160
August 13-18	The 5th Congress of Federation of Asian and Oceanian Biochemists	Seoul, Korea	Biochemical Society of Korea Seoul National University San 56-1 Shillim-dong Kwanak-gu, Seoul
August 18-19	International Symposium on Preparation of Functional Materials and Industrial Crystallization '89-Osaka	Osaka, Japan	Professor Yoshio Harano Applied Chemistry Faculty of Engineering Osaka City University 3-3-138 Sugimoto Sumiyoshi-ku, Osaka 558
August 19-23	The 4th Asian Congress of Fluid Mechanics	Hong Kong	Professor N.W.M. Ko 4ACFM Secretariat c/o Department of Mechanical Engineering University of Hong Kong Pokfulam Road, Hong Kong
August 20-25	The 6th International Symposium on Novel Aromatic Compounds (ISNA-6) 20-F100-J300	Osaka, Japan	Chemical Society of Japan 1-5 Kanda-Surugadai Chiyoda-ku, Tokyo 101
August 20-25	Protein Engineering '89	Kobe, Japan	Secretariat: Protein Engineering '89 Registration Office c/o JTB Communications, Inc. New Kyoto Center Building 5F Higashi-Shirokoji Shimogyo-ku, Kyoto 600
August 20-25	The 9th International Conference on Crystal Growth (ICCG) 48-F250-J550	Sendai, Japan	Secretariat: 9th International Conference on Crystal Growth c/o Inter Group Corp. 8-5-32 Akasaka Minato-ku, Tokyo 107
August 21-26	The 14th International Conference on High Energy Accelerators	Tsukuba, Japan	Mr. Kitagawa National Laboratory for High Energy Physics 1-1 Ooho Tsukuba-shi, Ibaraki 305
August 22-25	1989 International Symposium on Antennas and Propagation, Japan (ISAP '89)	Tokyo, Japan	Dr. Takashi Katagi Mitsubishi Electric Corp. 325 Kamimachiya Kamakura 247
August 22-26	The 10th International Symposium on Nuclear Quadrupole Resonance Spectroscopy	Takayama, Japan	Dr. Tetsuo Asaji The Secretary of Xth ISNQRS Department of Chemistry, PC II Faculty of Science Nagoya University Chikusa, Nagoya 464-01
August 25-28	The 7th International Conference on Composite Materials (ICCM-7)	Beijing, People's Republic of China	Tu Dezheng China Society of Aeronautics and Astronautics 67 South Street Jiao Daokou, Beijing

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August 25-28	International Conference on Calorimetry and Chemical Thermodynamics (IUPAC)	Beijing, People's Republic of China	Professor Hu Ri-heng Institute of Chemistry Academia Sinica Beijing
August 26-31	The 7th International Summer School on Crystal Growth	Zao, Japan	Professor H. Komatsu ISSCG-7 Chairperson c/o Inter Group Corp. Akasaka Yamakatsu Bldg 8-5-32 Akasaka Minato-ku, Tokyo 107
August 27-31	The 3rd International Symposium on Foundation of Quantum Mechanics--In the Light of New Technology (ISQM-Tokyo '89) NA-F50-J60	Tokyo, Japan	Professor H. Ezawa Department of Physics Gakushuin University Mejiro, Toshima-ku, Tokyo 171
August 27- September 1	The 5th International Symposium on Microbial Ecology (5th ISME) 73-F600-J600	Kyoto, Japan	Organizing Committee of 5th International Symposium on Microbial Ecology c/o Inter Group Corporation 8-5-32 Akasaka Minato-ku, Tokyo 107
August 28-30	The 1st ISSP International Symposium on the Physics and Chemistry of Organic Superconductors	Tokyo, Japan	Professor Saito The Institute for Solid State Physics University of Tokyo 7-22-1 Roppongi Minato-ku, Tokyo 106
August 28-31	International Symposium on Computational Fluid Dynamics--Nagoya, 1989 (ISCF-Nagoya 1989)	Nagoya, Japan	Professor Michiru Yasuhara Department of Aerospace Engineering Nagoya University Furo-cho, Chikusa-ku, Nagoya 464-01
August 28-31	The 5th International Symposium on Robotics Research	Tokyo, Japan	Department of Mechanical Engineering Faculty of Engineering University of Tokyo 7-3-1 Hongo Bunkyo-ku, Tokyo 113
August 28- September 1	The 11th International Conference on Magnet Technology	Tsukuba, Japan	T. Haruyama National Laboratory for High Energy Physics Oho-machi, Tsukuba-shi, Ibaraki 305
August 28- September 4	International Conference on Coordination Chemistry	Brisbane, Australia	Professor Hawkins Department of Chemistry University of QLD St. Lucia QLD 4067
August 29-31	Perpendicular Magnetic Recording Conference '89 (PMRC '89)	[illegible], [illegible]an	Professor Masahiko Naoe Department of Physical Electronics Tokyo Institute of Technology 2-12-1 O-okayama Meguro-ku, Tokyo 152
August 29- September 1	The 2nd International Symposium on Antennas and EM Theory (ISAE '89)	Shanghai, People's Republic of China	Mao Yukuan Xidian University 2 Taibe Road Xi'an

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Date	Title/Attendance	Site	Contact for Information
August 29-September 2	Yamada Conference XXIV on Strongly Coupled Plasma Physics	Yamanashi, Japan	Professor Setsuo Ichimaru Department of Physics Faculty of Science Tokyo University 7-3-1 Hongo Bunkyo-ku, Tokyo 113
September 3-7	The 7th COMPUMAG Conference on the Computation of Electromagnetic Fields	Tokyo, Japan	T. Takagi COMPUMAG Secretariat Nuclear Engineering Research Laboratory Faculty of Engineering University of Tokyo Tokai, Ibaraki 319-11
September 4-6	IEEE International Workshop on Intelligent Robots and Systems '89 (IROS '89): The Automotive Mobile Robot and Its Application	Tsukuba, Japan	Professor Shin'ichi Yuta University of Tsukuba Institute of Information Science and Electronics Tsukuba 305
September 4-6	The 1st International Marine Biotechnology Conference	Tokyo, Japan	Professor Isao Karube, Secretary General The Japanese Society for Marine Biotechnology c/o System Research Center Co., Ltd. 505 Asahi Toranomon Building 3-18-6 Toranomon Minato-ku, Tokyo 105
September 4-6	The 4th International Symposium on the Physical Metallurgy of Cast Iron (SCI-4) 10-F50-J100	Tokyo, Japan	Secretariat: The 4th International Symposium on Physical Metallurgy of Cast Iron c/o Simul International, Inc. Kowa Building No. 9 1-8-10 Akasaka Minato-ku, Tokyo 107
September 4-8	The 7th International Conference on Liquid and Amorphous Metals 30-F120-J280	Kyoto, Japan	Professor Hirohisa Endo Department of Physics, Faculty of Science Kyoto University Oiwake-cho, Kita-Shirakawa Sakyo-ku, Kyoto 606
September 4-8	ISES Solar World Congress 1989 Kobe 65-F400-J400	Kobe, Japan	Secretariat: ISES Solar World Congress 1989 c/o International Communications, Inc. Kasho Building 2-14-9 Nihonbashi Chuo-ku, Tokyo 103
September 4-8	Beijing International Conference on High Tc Superconductivity	Beijing, People's Republic of China	Professor Z.X. Zhao Organizing Committee (BHTSC '89) The Institute of Physics Chinese Academy of Sciences P.O. Box 603 Beijing 100080
September 5-7	International Conference on Zinc and Zinc Alloy Coated Steel Sheet 20-F50-J150	Tokyo, Japan	Secretariat of GALVATECH '89 Iron and Steel Institute of Japan 1-9-4 Otemachi Chiyoda-ku, Tokyo 100
September 5-8	1989 Beijing International Symposium on Cement and Concrete (2nd BISCC)	Beijing, People's Republic of China	Mr. Zhaogi Wu, Organizing Secretary China Building Materials Academy Guanzhuang, East Suburb, Beijing 100024
September 6-8	ACD&D '89 International Symposium on Advanced Computers for Dynamics and Design '89	Tsuchiura, Japan	Professor Akio Nagamatsu Chairman, The ACD&D Organizing Committee The Japan Society of Mechanical Engineers 2-4-9 Yoyogi Shibuya-ku, Tokyo 151

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Date	Title/Attendance	Site	Contact for Information
September 6-11	International Metal Hot Process Exhibition	Tianjin, People's Republic of China	Tianjin International Exhibition Corp. Binsui Road, Hexi District Tianjin
September 8-10	1989 International Symposium on Electromagnetic Compatibility 26-F170-J400	Nagoya, Japan	Secretariat: International Symposium on Electromagnetic Compatibility c/o Department of Information and Computer Sciences Toyohashi University of Technology 1-1 Tenpaku-cho, Aza-Hibarigaoka Toyohashi, Aichi 440
September 9-14	The 2nd International Symposium on Rare Earths Spectroscopy	Changchun, People's Republic of China	Professor Su Qiang Changchun Institute of Applied Chemistry Academia Sinica Changchun 130022
September 11-12	Testing Electromagnetic Analysis Methods Workshops for Eddy Current Code Comparison 8-F30-J50	Okayama, Japan	Faculty of Engineering Okayama University 3-1-1 Tsushima-Naka Okayama 700
September 12-14	Thermtech Asia 89	Hong Kong	International Symposia and Exhibitions Ltd. Queensway House 2 Queensway Redhill, Surrey RH1 1QS, UK
September 12-16	The 2nd International Conference & Workshop on Electromagnetic Interference & Compatibility (INCEMIC)	Bangalore, India	Professor G.R. Nagabhushana High Voltage Engineering Dept. Indian Institute of Science Bangalore 560 0 12
September 13-17	China-Japan Bilateral Symposium on Polymer Science and Materials	Gangzhou, People's Republic of China	The Society of Polymer Science, Japan 5-12-8 Ginza Chuo-ku, Tokyo 104
September 17-22	International Conference on the Science and Technology of DEFECT CONTROL IN SEMICONDUCTORS-Yokohama 21st Century Forum	Yokohama, Japan	IC-STDCS c/o Lab. Physics of Crystal Defects Institute for Materials Research Tohoku University 2-1-1 Katahira, Sendai 980
September 17-22	The 40th Meeting of International Society of Electrochemistry 42-F200-J540	Kyoto, Japan	Secretariat 40th Meeting of International Society of Electrochemistry c/o Kyoto International Conference Hall Takaragaike, Sakyo-ku, Kyoto 606
September 22-25	The 3rd International Symposium on Defect Recognition and Image Processing for Research and Development of Semiconductors (DRIP III)	Tokyo, Japan	Professor Tomoya Ogawa Department of Physics Gakushuin University Mejiro, Tokyo 171
September 24-28	The 6th International Symposium on Passivity - Passivation of Metals and Semiconductors	Sapporo, Japan	Dr. Norio Satoh Faculty of Engineering Hokkaido University Nishi 8-chome, Kita 13-jo Sapporo-shi 060
September 25-28	The 5th International Conference on Numerical Ship Hydrodynamics 15-F80-J120	Hiroshima (tentative)	Faculty of Engineering Hiroshima University Shitami Saijo-cho Higashi-Hiroshima 724

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September 25-28	Nuclear Inter JURA 1989 25-F220-J50	Tokyo, Japan	Secretariat of Nuclear Inter JURA 1989 c/o Sansei International, Inc. 4F, Fukide Dai 2 Building 4-1-21 Toranomon Minato-ku, Tokyo 105
September 25-28	ELA XI Biennial International Symposium 20-F200-J200	Tokyo, Japan	Secretariat: ELA c/o Tokyo Medical College 6-7-1 Nishi-Shinjuku Shinjuku-ku, Tokyo 160
September 25-29	The 16th International Symposium on Gallium Arsenide and Related Compounds	Karuizawa, Japan	Secretary: Professor T. Katoda Research Center for Advanced Science and Technology University of Tokyo 4-6-1 Komaba Meguro-ku, Tokyo 153
September 26-28	International Symposium on Optical Memory 1989	Kobe, Japan	Secretariat c/o Business Center for Academic Societies Japan 3-23-1 Hongo Bunkyo-ku, Tokyo 113
October 1-4	The 7th World Congress of the International Society for Artificial Organs	Sapporo, Japan	The 7th International Society for Artificial Organs c/o International Communications Inc. Kasho Bldg 2-14-9 Nihonbashi Chuo-ku, Tokyo 103
October 2-4	Today's Technology for the Mining and Metallurgical Industries 30-F300-J300	Kyoto, Japan	MMIJ/IMM Joint Symposium Office Mining and Metallurgical Institute of Japan Nogizaka Building 9-6-41 Akasaka Minato-ku, Tokyo 107
October 2-4	MMIJ/IMM Joint Symposium (Kyoto) 30-F300-J300	Kyoto, Japan	Mining and Materials Processing Institute of Japan Nogizaka Bldg 9-6-41 Akasaka Minato-ku, Tokyo 107
October 2-5	The 3rd International Conference on Computer Applications in Production and Engineering (CAPE '89)	Tokyo, Japan	Secretariat c/o Conference Department Business Center for Academic Societies Japan 3-23-1 Hongo Bunkyo-ku, Tokyo 113
October 3-5	The 10th Meeting of World Society for Stereotactic and Functional Neurosurgery 20-F200-J300	Maebashi, Japan	Department of Neurosurgery Gumma University, School of Medicine 3-39 Showa-machi Maebashi 371
October 4-6	International Meeting on Advanced Processing and Characterization Technology (APCT '89)	Tokyo, Japan	Professor Kunio Tada Department of Electronic Engineering University of Tokyo 7-3-1 Hongo Bunkyo-ku, Tokyo 113
October 4-6	The 20th International Symposium on Industrial Robots	Tokyo, Japan	Japanese Society of Industrial Robots 3-5-8 Shibakoen Minato-ku, Tokyo 105

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October 9-12	TUBE '89 International Congress and Exhibition	Singapore	International Tube Association P.O. Box 84 Leamington Spa, Warwickshire CV32 5FX, UK
October 10-19	International Training Course on Biomembranes	Beijing, People's Republic of China	Professor F.Y. Yang Department of Biomembranes Institute of Biophysics Academia Sinica Beijing, 10080 China
October 11-17	ACHEMASIA'89	Beijing, People's Republic of China	
October 11-17	The 1st Asian Congress on Chemical Engineering and Biotechnology	Beijing, People's Republic of China	c/o DECHEMA Theodor-Heuss-Allee 25 P.O. Box 97 01 46 D-6000 Frankfurt-Main 97, FRG
October 12-14	The 1st International Conference on Higher Nervous Functions	Osaka, Japan	Behavioral Physiology Faculty of Human Sciences Osaka University 1-2 Yamadaoka Fukita-shi, Osaka 565
October 15-18	The 9th International Display Research Conference - Japan Display '89 27-F200-J500	Kyoto, Japan	Secretariat of Japan Display '89 c/o Japan Convention Services, Inc. 4F, Nippon Press Center Bldg 2-2-1 Uchisaiwai-cho Chiyoda-ku, Tokyo 100
October 17-19	The 1st International Conference on Music Perception and Cognition	Kyoto, Japan	ICMPC Secretariat Department of Music Kyoto City University of Arts Kutsukake, Ohe Nishikyo-ku, Kyoto 610-11
October 17-22	CIS '89 Tokyo/International Symposium on Chromatography	Tokyo, Japan	Professor Tadao Hoshino, Secretary General of CIS '89 Division of Chemotherapy Pharmaceutical Institute, School of Medicine Keio University 35 Shinanomachi Shinjuku-ku, Tokyo 160
October 18-21	The 1st ANAIC International Conference on Silicon and Tin	Kuala Lumpur, Malaysia	Professor V.G. Kumar Das Department of Chemistry University of Malaya 59100 Kuala Lumpur
October 22-26	International Conference on Semiconductor and Integrated Circuit Technology	Beijing, People's Republic of China	Continuing Education in Engineering University Extension University of California 2223 Fulton Street Berkeley, CA 94720
October 23-25	The 10th International Conference on Assembly Automation	Kanazawa, Japan	Conference Manager (ICAA-10) IFS Conferences 35-39 High Street, Kempston Bedford MK42 7BT England
October 23-25	The 2nd International Waste Management Conference	Kyoto, Japan	Mr. R. Kohout Ontario Hydro 700 University Ave. Toronto, Ontario M5G 1X6 Canada

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Date	**Title/Attendance**	**Site**	**Contact for Information**
October 23-26	International Conference on System Simulation and Scientific Computing	Beijing, People's Republic of China	
October 23-27	International Conference on Coal Science	Tokyo, Japan	Secretariat for ICCS Coal Conversion Department New Energy Development Organization (NEDO) Sunshine 60 Building 3-1-1 Higashi-Ikebukuro Toshima-ku, Tokyo 170
October 23-28	The 2nd World Congress on Non-Metallic Minerals	Beijing, People's Republic of China	Before 31 August 1989: WCNMM 1989 Wuhan University of Technology Wuhan, Hubei, China After 31 August 1989: WCNMM 1989 Chinese Silicate Society Bai [illegible]n Zhuang Beijing, China
October 24-26	Electric Energy Conference 1989	Sydney, Australia	Conference Manager The Institution of Engineers, Australia 11 National Circuit Barton, ACT 2600
October 25-27	IFAC/IFORS/IAEE International Symposium on Energy Systems, Management and Economics (ESME 89)	Tokyo, Japan	Dr. Kenji Yamaji Central Research Institute of Electric Power Industry 1-6-1 Ohtemachi Chiyoda-ku, Tokyo 100
October 25-28	International Sheet Metal Working and Forming Exhibition	Hong Kong	Mack-Brooks Exhibitions Ltd. Forum Place Hatfield, Hert AL10 ORN, UK
October 26-28	ACEAN Polymer Symposium 10-F30-J30	Osaka, Japan	Institute of Scientific and Industrial Research, Osaka University 8-1 Mihogaoka Ibaraki-City, Osaka 567
October 29-November 3	International Symposium on Polymers for Microelectronics (PME '89)	Tokyo, Japan	Professor Sei-ichi Tagawa Research Center for Nuclear Science and Technology University of Tokyo Tokai, Ibaraki 319-11
October 30-November 2	IFAC (International Federation of Automatic Control) Workshop on Production Control in Process Industry	Osaka, Japan	PCPI '89 Secretary Dr. H. Nishitani Department of Information and Computer Sciences Osaka University 1-1 Machikaneyama Toyonaka, Osaka 560
November 1-5	International Symposium/Exhibition on Flame Retardants (IFRESEX '89)	Beijing, People's Republic of China	Mr. Niu Qingzhu Director of the Academic Exchange Dept. China Ordnance Society China
November 5-9	The 7th International Conference on Solid State Ionics	Hakone, Japan	
November 5-10	The 5th International Pacific Conference on Automotive Engineering	Beijing, People's Republic of China	IPC-5 Organizing Committee c/o Society of Automotive Engineers of China 16 Fuzingmenwai Street Beijing 100860

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November 5-11	The 7th International Conference on Solid State Ionics (SSI-7)	Hakone, Japan	Dr. T. Atake, Executive Secretary SSI-7 Secretariat Research Laboratory of Engineering Materials Tokyo Institute of Technology 4259 Nagatsuta-cho Midori-ku, Yokohama 227
November 6-10	Aluminum and Magnesium	Zhengzhou, People's Republic of China	Conference Office, IMM 44 Portland Place London W1N 4BR, UK
November 7-10	International Conference on Electronic Components and Materials (ICECM '89)	Beijing, People's Republic of China	Secretariat of ICECM '89 c/o Professor Zhou Zhigang Department of Chemical Engineering Tsinghua University Beijing 100084
November 7-10	The 2nd International Symposium on the Physical and Failure Analysis of Integrated Circuits	Singapore	Secretariat IPFA Symposium Communication International Associate Pte Ltd. 450 Alexandra Road #10-00 Inchcape House, Singapore 0511
November 13-14	International Superconductivity Symposium: Superconductivity and Ionic Character in Layered Compounds	Tokyo, Japan	Dr. Tesuro Nakamura Research Laboratory of Engineering Materials Tokyo Institute of Technology 4259 Nagatsuta-cho Midori-ku, Yokohama 227
November 13-14	SSI-7 Post Conference in Solid Oxide Fuel Cells '89 *Nagoya*	Nagoya, Japan	Dr. M. Dokiya National Chemical Laboratory for Industry Tsukuba, Ibaraki 305
November 14-16 (tentative)	Photo-Induced Surface Reactions	Kyoto, Japan	Professor Hiroshi Haneda Faculty of Engineering Kyoto University Yoshida Honmachi Sakyo-ku, Kyoto 606
November 14-16	The 1989 International Symposium on Noise and Clutter Rejection in Radar and Imaging Sensors (ISNCR-89)	Kyoto, Japan	Professor Tsutomu Suzuki Department of Electronics University of Electro-Communications Chofu-shi, Tokyo 182
November 14-16	International Symposium on Exploitation and Utilization of Titaniferrous Vanadio-Magnetite	Panzhihua, People's Republic of China	STiVM Secretariat Chinese Society of Metals 46 Dongsixi Dajie Beijing 100711
November 20-23	International Conference Evaluation of Materials Performance in Severe Environments-Evaluation and Development of Materials in Civil and Marine Uses 20-F80-J120	Kobe, Japan	International Conference Secretariat Conference and Editorial Department Iron and Steel Institute of Japan 1-9-4 Otemachi Chiyoda-ku, Tokyo 100
November 20-December 1	The 1st International Symposium and Exhibition of SAMPE JAPAN CHAPTER	Makuhari, Japan	SAMPE P.O. Box 2459 Covina, CA 91722

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November 22-24	Tencon 89	Bombay, India	Kirit J. Sheth, Chairman IEEE Bombay Section c/o Hakotoronics Pvt. Ltd. Dadoji Konddeo Cross Marg Bombay 400 027, India
November 22-28	International Conference on Plasma Physics 1989	New Delhi, India	P.K. Kaw, Director Institute for Plasma Physics Bhat, Gandhinagar Gujarat 382 424 India
November 27-28	Asia Vibration Conference '89	Shen Zhen, People's Republic of China	Professor Takuzo Iwatsubo Mechanical Engineering Faculty of Engineering Kobe University 1-1 Rokkodai-cho, Nada-ku Kobe-shi, Hyogo 657
November 28-December 1	1st Japan International SAMPE Symposium & Exhibition: New Materials and Processes for the Future	Chiba, Japan	1st Japan International SAMPE Symposium & Exhibition c/o The Nikkan Kogyo Shinbun, Ltd. 1-8-10 Kudan Kita Chiyoda-ku, Tokyo 102
December 4-8	The 4th International Conference on Fusion Reactor Materials	Kyoto, Japan	Professor S. Ishino General Chairman, ICFRM-4 Department of Nuclear Engineering University of Tokyo Bunkyo-ku, Tokyo 113
December 11-13	The 3rd International Workshop on Petri Nets and Performance Models (PNPM 89)	Kyoto, Japan	Dr. Shojiro Nishio Department of Applied Mathematics and Physics Faculty of Engineering Kyoto University Kyoto 606
December 11-15	The 10th Australasian Fluid Mechanics Conference	Melbourne, Australia	10AFMC c/o Professor A.E. Perry Department of Me[illegible]anical Engineering The University of Melbourne Parkville, Vict[illegible]a 3052
December 11-21	The 5th International Symposium on World Trends in Science and Technology Education	Manila, Philippines	Dr. Adracion D. Ambrosio IOSTE Symposium Chairman Philippine Science High School Diliman, Quezon City 1104

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January 22-26	International Conference on Recrystallization in Metallic Meterials	Wollongong, Australia	Metallurgical Society of AIME Conference Department 420 Commonwealth Drive Warrendale, PA 15086
February 4-9	The 17th International Symposium on the Chemistry of Natural Products (IUPAC)	New Delhi, India	Professor Sukh Dev Multi-Chem. Research Centre Nandesari, Baroda-39340
February 4-9	The 18th Australian Polymer Symposium	Bendigo, Australia	Dr. J.D. Wells Chemistry Department Bendigo CAE P.O. Box 1199 Bendigo 3550, Victoria

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February 5-9	International Workshop on Polarized Ion Source 10-F40-J20	Tsukuba, Japan	National Laboratory for High Energy Physics 1-1 Oho Tsukuba, Ibaraki-ken 305
March 1	Workshop on Advanced Motion Control	Yokohama, Japan	Professor Kohei Ohnishi Department of Electric Engineering Keio University 3-14-1 Hiycshi Kohoku, Yokohama 223
March 29-31	IEEE Industrial Electronics Society	Tokyo, Japan	Ohnishi Faculty of Science and Technology Keio University 3-14-1 Hiyoshi, Minato Kita-ku Yokohama-shi, Kanagawa 223
April 8-12	1990 International Topical Meeting on Optical Computing	Kobe, Japan	OC'90 Secretariat Business Center for Academic Societies Japan (BCASJ) 3-23-1 Hongo Bunkyo-ku, Tokyo 113
April 23-25	The 3rd Japan-China Joint Conference on Fluid Machinery	Osaka, Japan	Professor Yutaka Miyake Department of Mechanical Engineering Faculty of Engineering Osaka University 2-1 Yamada-Oka Suita, Osaka 565
April 23-27	Nankai Conference: International Conference on Physics Education Through Experiments	Tianjin, People's Republic of China	Professor Zhao Jing-yuan Department of Physics Nankai University Jianjin
May 19-26	The 27th International Navigation Congress 62-F500-J500	Osaka, Japan	Japan Organizing Committee for 27th International Navigation Congress of PIANC c/o Port and Harbor Bureau City of Osaka 2-8-24 Chikko Minato-ku, Osaka 552
May 29- June 1	The International Conference on Manufacturing Systems and Environment - Looking Forward to the 21st Century	Tokyo, Japan	T. Nakajima The Japan Society of Mechanical Engineers Sanshin Hokusei Building 2-4-9 Yoyogi Shibuya-ku, Tokyo 151
June 26-30	International Symposium on High Temperature Corrosion and Protection	Shenyang, People's Republic of China	Professor Man Yongfa Institute of Metal Research Academia Sinica 2-6 Wenhua Road Shenyang, Liaoning Province China
July 1-6	The 3rd International Conference on Technology of Plasticity (3rd ICTP)	Kyoto, Japan	The Organizing Committee 3rd ICTP c/o The Japan Society for Technology of Plasticity Torikatsu Building 5-2-5 Roppongi Minato-ku, Tokyo 106
July 15-21	The 10th International Congress of Nephrology 10-F1,000-J4,000	Tokyo, Japan	Japanese Society of Nephrology c/o 2nd Department of Internal Medicine School of Medicine, Nippon University 30-1 Oyaguchi-kamicho Itabashi-ku, Tokyo 173

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July 16-21	ISEC '90 International Solvent Extraction Conference	Kyoto, Japan	Conference Secretariat ISEC '90 Department of Chemistry Science University of Tokyo Kagurazaka, Shinjuku-ku, Tokyo 162
July 30-August 2	The 15th International Conference on International Association on Water Pollution Research and Control	Kyoto, Japan	Japan Society on Water Pollution Research and Control Yotsuya New Mansion 12 Honshiocho Shinjuku-ku, Tokyo 173
August 12-17	The 15th International Carbohydrate Symposium	Yokohama, Japan	Dr. Ishido, General Secretary Faculty of Science Tokyo Institute of Technology Ookayama, Meguro-ku, Tokyo 152
August 21-29	International Congress of Mathematicians 1990 84-F1,500-J1,500	Kyoto, Japan	ICM 90 Secretariat c/o International Relations Office Research Institute for Mathematical Sciences Kyoto University Kitashirakawa Oiwake-cho Sakyo-ku, Kyoto 606
August 22-24	1990 International Conference on Solid State Devices and Materials	Sendai, Japan	c/o Business Center for Academic Societies Japan Crocevia Building 2F 3-23-1 Hongo Bunkyo-ku, Tokyo 113
August 23-30	V International Congress of Ecology 62-F900-J1,000	Yokohama, Japan	Secretary General's Office for INTECOL 1990 c/o Institute of Environmental Science and Technology Yokohama National University 156 Tokiwadai Hodogaya-ku, Yokohama 240
September 16-22	IUMS Congress: Bacteriology and Mycology - Osaka, Japan - 1990 71-F2,000-J3,500	Osaka, Japan	Secretariat: IUMS Congress c/o Institute of Medical Science University of Tokyo 4-6-1 Shirokanedai Minato-ku, Tokyo 108
September 19-22	The 2nd World Congress on Particle Technology	Kyoto, Japan	Professor G. Jimbo Department of Chemical Engineering Nagoya University Furo-cho, Chikusa-ku, Nagoya 464-01
September 24-27	The 6th International Congress on Polymers in Concrete	Shanghai, People's Republic of China	ICPIC-90 Secretariat c/o Associate Professor Tan Muhua Institute of Materials Science and Engineering Tongji University Shanghai
September 24-28	The 3rd International Aerosol Conference	Kyoto, Japan	Professor Kanji Takahashi, General Secretary Institute of Atomic Energy Kyoto University Uji, Kyoto 611
September (tentative)	The 15th International Congress on Microbiology 57-F2,500-J2,500	Osaka, Japan	Preliminary Committee of International Congress of Microbiology c/o JTB Creative Inc. Daiko Building 3-2-14 Umeda Kita-ku, Osaka 530

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Date	Title/Attendance	Site	Contact for Information
October 15-19	The 4th International Symposium on Marine Engineering (ISME KOBE '90)	Kobe, Japan	The Marine Engineering Society in Japan Hibiya Osaka 2nd Bldg 1-2-2 Uchisaiwai-cho Chiyoda-ku, Tokyo 100
October 21-26	The 6th International Iron and Steel Congress 50-F300-J500	Nagoya, Japan	International Conference Department Iron and Steel Institute of Japan 3F, Keidanren Kaikan 1-9-4 Otemachi Chiyoda-ku, Tokyo 100
October 22-26	International Conference on Information Technology in Connection with 30th Anniversary Celebration of Information Processing Society of Japan N.A.-F200-J1,000	Osaka, Japan	Secretariat: International Conference on Information Technology c/o Simul International, Inc. Kowa Building, No. 9 1-8-10 Akasaka Minato-ku, Tokyo 107
October 29-November 1	Japan International Tribology Conference Nagoya - '90 N.A.-F100-J500	Osaka, Japan	Secretariat: Japan ITC Nagoya - '90 c/o Toyota Technological Institute 2-chome, Hisakata Tempaku-ku, Nagoya 468
November 4-8	International Symposium on Carbon, 1990: "New Processing and New Applications"	Tsukuba, Japan	The Carbon Society of Japan Saito Building 2F 2-16-13 Yujima Bunkyo-ku, Tokyo 113
November 26-29	The 3rd International Polymer Conference (3rd IPC) 5-F100-J200	Nagoya, Japan	IPC Secretariat c/o Society of Polymer Science, Japan 5-12-8 Ginza Chuo-ku, Tokyo 104
November 26-29	The 5th International Photovoltaic Science and Engineering Conference (International PVSEC-5)	Kyoto, Japan	Professor Junji Saraie Secretariat of International PVSEC-5 c/o Japan Convention Services, Inc. Nippon Press Center Building 2-2-1 Uchisaiwai-cho Chiyoda-ku, Tokyo 100
1990 (tentative)	Chemeca 1990 Applied Thermodynamics	New Zealand	Conference Manager The Institution of Engineers, Australia 11 National Circuit Barton, ACT 2600

1991

Date	Title/Attendance	Site	Contact for Information
February 7-12	The 10th International Conference on Offshore Mechanics and Arctic Engineering	Seoul, Korea	Korea Cmt for Ocean Resources and Engineering Dong-A University 840 Sahagu Pusan, Korea
February 10-15	POLYMER '91: International Symposium on Polymer Materials	Melbourne, Australia	Dr. G.B. Guise P.O. Box 224 Belmont, VIC 3216, Australia
July 7-12	The 16th International Conference on Medical and Biological Engineering (ICMBE) 45-F600-J1,400	Kyoto, Japan	Japan Society of Medical Electronics and Biological Engineering 2-4-16 Yayoi Bunkyo-ku, Tokyo 113

1991

Date	Title/Attendance	Site	Contact for Information
July 7-12	The 9th International Congress on Medical Physics (ICMP) 45-F600-J1,400	Kyoto, Japan	National Institute of Radiological Science 4-9-1 Anagawa Chiba 260
July 24-26	The 3rd International Conference on Residual Stresses (ICRS-3)	Tokushima, Japan	Society of Materials Sciences, Japan 1-101 Yoshida Izumidono-cho Sakyo-ku, Kyoto 606
July 24-30	The 17th International Conference on the Physics of Electronic and Atomic Collisions	Brisbane, Australia	Dr. W.R. Newell Department of Physics University College of London Gower Street London WC1E 6BT UK
July 29-August 2	The 6th International Conference on Mechanical Behavior of Materials (ICM-6)	Kyoto, Japan	Society of Materials Sciences, Japan 1-101 Yoshida Izumidono-cho Sakyo-ku, Kyoto 606
August 25-31	International Congress on Analytical Science-1991 (ICAS '91)	Chiba, Japan	The Japan Society for Analytical Chemistry Rm 304 Gotanda Sun Heights 1-26-2 Nishi Gotanda Shinagawa-ku, Tokyo 141
August (tentative)	The 16th International Conference on Medical and Biological Engineering (ICMBE)	Kyoto, Japan (tentative)	Japan Society of Medical Electronics and Biological Engineering 2-4-16 Yoyogi Bunkyo-ku, Tokyo 113
Undecided 1991	The 9th International Conference on Hot Carriers in Semiconductors 10-F50-J100	Osaka or Nara, Japan	Department of Electronics Osaka University 2-1 Yamada-Oka Suita, Osaka 565

1992

Date	Title/Attendance	Site	Contact for Information
May 10-15	NETWORKS '92: The 5th International Network Planning Symposium 20-F250-J100	Undecided, Japan	NTT Telecommunication Networks Laboratories 3-9-11 Midori-cho Musashino-shi, Tokyo 180
October 26-30	The 14th International Switching Symposium (ISS '92) 60-F1,200-J800	Yokohama, Japan	NTT Communication Switching Laboratories 3-9-11 Midori-cho Musashino-shi, Tokyo 180
Autumn	XIVth International Switching Symposium (ISS '92)	(to be decided)	Institute of Electronics, Information and Communication Engineers (IEICE) Kikai Shinko Kaikan 3-5-8 Shiba-koen Minato-ku, Tokyo 105

1993

Date	Title/Attendance	Site	Contact for Information
1993 (tentative)	International Federation of Automatic Control Congress	Sydney, Australia	Conference Manager The Institution of Engineers, Australia 11 National Circuit Barton, ACT 2600

1994			
Date	**Title/Attendance**	**Site**	**Contact for Information**
Tentative	XXX International Conference on Coordination Chemistry	Kyoto, Japan	Professor Hitoshi Ohtaki Coordination Chemistry Laboratories Institute for Molecular Science Myodaiji-cho, Okazaki 444

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